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The Bradford Oil Field
Pennsylvania and New York

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BRADFORD, PENNSYLVANIA—Looking west from slope of Mount Raub.

THE BRADFORD OIL FIELD PENNSYLVANIA and NEW YORK

By CHAS. R. FETTKE

●

INTRODUCTION

The Bradford Oil Field of northwestern Pennsylvania and adjacent area in New York State produced 352,700,000 barrels of oil from 1871 to 1936, inclusive. The methods of production now in use probably will raise the total output to 500,000,000 barrels in the future. World-wide attention in recent years has been attracted to the remarkable success that has been attained in the application of artificially-conducted water drives as a means of increasing the extraction of oil from a pool that had almost reached the economic limit by ordinary production methods. Almost all the Bradford production has come from a single horizon, the Bradford Third sand, which has proved to be productive over a continuous area of 84,000 acres. This gives the Bradford pool not only a major rank among the great oil pools of the United States, eighth in 1934[1] from the standpoint of total production, but also places it second with respect to total continuous productive area, the recently discovered East Texas pool, with an area of 116,580 acres,[2] being the only one that is larger.

LOCATION AND SIZE OF THE BRADFORD FIELD

The Bradford Oil Field lies mainly in the north-central part of McKean County, Pennsylvania, the third from the west on the northern tier of counties. The field extends a short distance over into Cattaraugus County, New York, approximately 14 percent of the area of the Bradford pool being in that State. The location of the field is shown in Figure 1.

The Bradford field is included in the rectangle, 21 miles long north and south, and 18 miles wide east and west, which is outlined in heavy black lines in Figure 1. The Bradford pool proper occupies 84,000 acres. Practically all its production comes from the Bradford Third sand. Smaller detached pools, which are also productive in the Bradford Third sand and total 8,500 acres, lie around the eastern and southern margins of the main pool. In addition, several other small pools, in part overlapping those already mentioned, yield gas and some oil from sands occurring above and below the Bradford Third sand.

PURPOSE OF INVESTIGATION

By 1926 the success attained by water-flooding operations in the Bradford field had reached the stage where more and more outside as well as

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[1] The Oil and Gas Journal, January 31, 1935, p. 6.

[2] C. E. Reistle, Jr., East Texas production, drilling and production practice in 1934: American Petroleum Institute, p. 96, 1935.

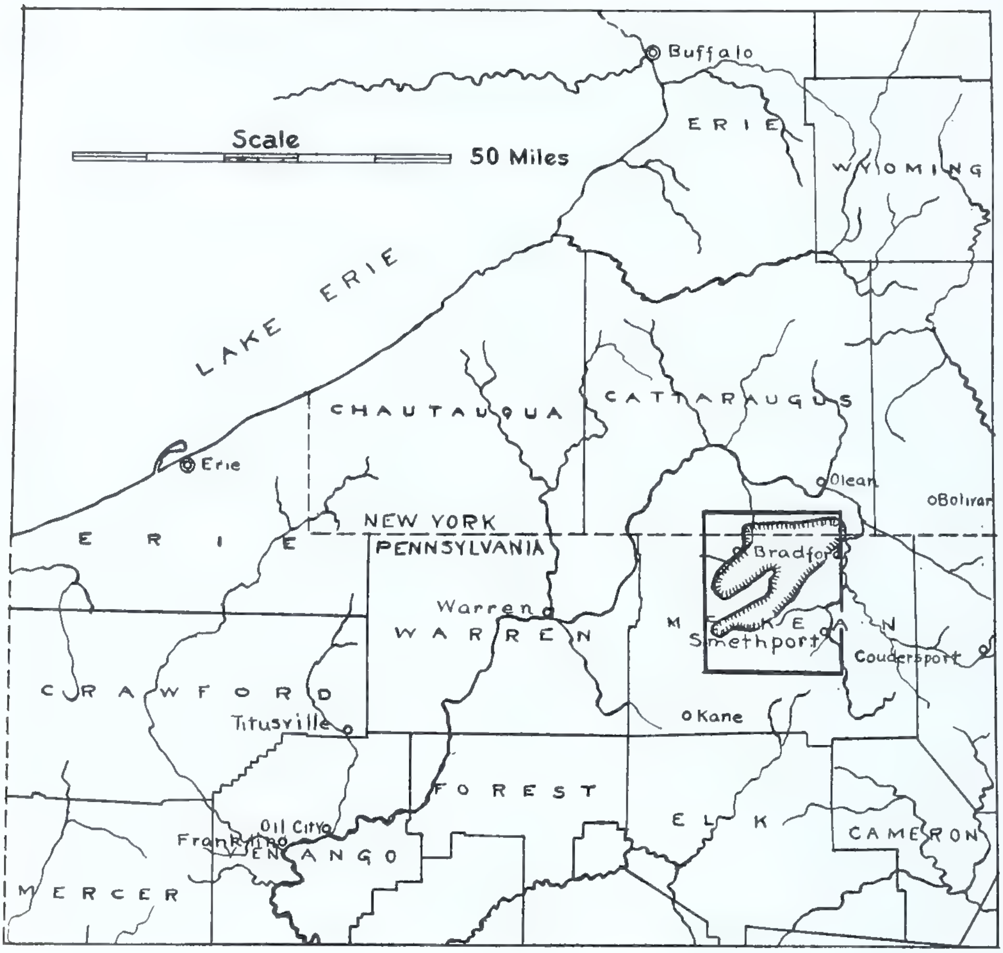

FIGURE 1. **Map showing location of Bradford district and Bradford oil pool.**

local capital seeking profitable investment, was becoming available for the further development of this system of oil production. It was realized by those engaged in the production of oil in the district that the methods of water-flooding in use at that time could no doubt be greatly improved. Flooding operations were not uniformly successful over the entire area of the pool. While in many instances this could be attributed primarily to variations in sand conditions, there were many others where lack of success seemed to be due to lack of proper technique in applying the water-drive. It was felt that a more detailed knowledge of the geology of the district and, particularly, more precise information in regard to the nature of the reservoir rock and the subsurface structure than was at that time available, were essential to further improvements in the methods of applying the water-drive. The Pennsylvania Topographic and Geologic Survey, at the request of the Northwestern Pennsylvania Oil Producers Association, therefore, undertook the task of making a detailed geological survey of the Bradford Oil Field. The writer, who had previously studied the relation of sand conditions to the application of the air-drive in the Venango district for the same organization, was engaged to take charge of this work.

METHOD OF INVESTIGATION

On account of the important role that structure usually plays in the occurrence of oil and gas deposits, it was felt that the preparation of a rather detailed structure map of the area outlined by the rectangle shown in Figure 1 was essential to the proper understanding of the geological problems of the district as related to the occurrence and production of oil. A detailed structure map of the area has, therefore, been prepared. Structure contours, using a ten-foot interval, have been drawn on the top of the Bradford Third sand. The United States Geological Survey and the Pennsylvania Department of Highways had previously established accurate bench marks over most of the area at convenient intervals for checking the stadia traverses which were run over the entire area, using a plane table and a Gurley explorer's alidade. Elevations were checked usually within less than one foot. The original mapping, from which the detailed structure map shown on Plate A was compiled, was done on a scale of 500 feet to the inch. This large scale was necessary on account of the close spacing of the wells over much of the area. It would have been difficult to identify individual wells on the plane-table sheets and assign the proper records to them if a smaller scale had been used. Elevations were taken on 3,100 wells and elevations on an additional 2000 were obtained from companies and individual operators. In the latter case the datum plane used was checked in each instance and adjustments were made where necessary. The base map of Plate A was compiled from maps of Paul P. Lyon, the Sloan and Zook Company, W. A. Heath and T. O. Glenn, Jr., J. Opperman, and the United Natural Gas Company.

Data for preparing the areal geology map of the Bradford quadrangle were obtained in conjunction with the subsurface structure mapping. Although the region is one of rugged topography, it is, for the most part, covered with soil and heavily wooded so that good outcrops are scarce. No well-defined key horizons crop out in this part of Pennsylvania that can be used for mapping structure. As many elevations as possible were obtained on the base of the Olean conglomerate and sandstone and the top of the uppermost red shales in the Cattaraugus formation in order to determine to what extent these horizons can be used in adjacent areas for predicting subsurface structures.

Little time was available for collecting fossils. Paul D. Torrey, while in the employ of the United States Geological Survey, had collected fossils from several geologic horizons in the district during the spring of 1926. All these collections were submitted to Charles Butts of the United States Geological Survey for identification and, through the courtesy of that organization, the results have been made available for this report.

Information in regard to the subsurface stratigraphy was obtained from the examination of complete sets of samples of drill cuttings from several wells and the study of numerous well records.

Much attention was paid to the study of the Bradford sand itself. Cores of the sand were obtained from nearly all parts of the field. Porosity determinations, screen analyses, and, in many instances, saturation and permeability tests were made. The core studies were supplemented by the examination of numerous sets of samples of the drill cuttings of the sand from various parts of the field. Many of the operators furnished production data which, in so far as has been feasible, have been correlated with geological conditions and operating methods.

Samples of the oil representative of all parts of the field were taken. These have been analyzed by the United States Bureau of Mines at the Bartlesville, Oklahoma, station through a cooperative arrangement made by the Pennsylvania Topographic and Geologic Survey. Samples of the oil field waters have similarly been analyzed by the United States Geological Survey.

The field work on which this report is based was done during the summers of 1926, 1927 and 1929. Portions of the summers of 1928, 1930, 1932, 1933, and 1934 were devoted to the compilation of data at the offices of the numerous companies and individuals engaged in the production of oil in the Bradford field. All the laboratory and office work was done by the writer at the Carnegie Institute of Technology, Pittsburgh, Pa. during those periods that were not taken up by his duties as Professor of Geology and Mineralogy.

ACKNOWLEDGMENTS

During the summers of 1926, 1927, and 1929 the writer was assisted in the field by W. A. Copeland, formerly assistant professor of Geology and Mineralogy at the Carnegie Institute of Technology, who did all of the instrumental work in connection with the plane - table mapping. During the summer of 1930, Mr. Copeland also examined the numerous sets of samples of drill cuttings of the Bradford sand which had been collected during the course of the investigation and made the screen analyses which are included in this report. W. H. Seifert acted as assistant to Mr. Copeland during the summer of 1929 and spent part of the summer of 1930 assisting the writer in compiling the data for the structure map, Plate A. To both these men the writer is especially indebted for efficient service.

Through cooperative arrangements, the United States Bureau of Mines analyzed the samples of crude oil collected in connection with the investigation, and the United States Geological Survey, the samples of oil field waters. Charles Butts of the latter organization examined several collections of fossils from the district and furnished helpful advice in connection with some of the correlation problems. The porosity, permeability, and saturation determinations on cored samples of the Bradford sand were made by the writer in the laboratories of the Carnegie Institute of Technology. E. E. Gallagher and Eric W. Kerr assisted with the permeability determinations. Students at the Carnegie Institute of Technology, working under grants received from F.E.R.A. and N.Y.A. funds, assisted with the calculating and drafting.

An investigation of this kind could be carried on successfully only by having behind it the whole-hearted cooperation of the host of companies and individuals who are actively engaged in the production of oil in the Bradford field. The writer is grateful to be able to say that in practically no instance was information essential to the work withheld. The active interest manifested by the officers of the Northwestern Pennsylvania Oil Producers Association, has also been greatly appreciated. To Paul P. Lyon, civil engineer, of Bradford, the writer is indebted for permission to use the property map, which he had compiled of the Bradford field, as a base map for plotting the structure.

While it is not possible to list the names of all the literally hundreds of individuals who contributed data for this report, it is only fitting that the valuable assistance of the following men who contributed so generously from their store of knowledge and experience, as well as of their time, should be here acknowledged: D. T. Andrus, Homer G. Barcroft, J. W. Bird, A. E. Booth, Robert B. Bossler, George Bovaird, Jr., Frank M. Brewster, E. E. Bryner, E. H. Bryner, John K. Cochran, P. H. Curry, H. K. Dougherty, Wm. N. Davis, Leonard Eberl, Frank E. Eckert, C. L. Faust, Jr., N. V. V. Franchot, R. M. Haskell, William J. Healey, W. L. Horner, T. H. Kennedy, R. C. Lloyd, C. B. McClintock, Parker L. Melvin, John Messer, J. G. Montgomery, Jr., Jerry B. Newby, F. H. Newell, K. B. Nowels, Wilson K. Page, L. S. Panyity, Cornell N. Pfohl, Jr., Paul M. Phillippi, W. T. Piper, Harry N. Ryder, Arthur C. Simmons, D. B. Tanner, O. F. Thompson, T. P. Thompson, Jr., Paul D. Torrey, Joseph B. Umpleby, George E. Welker, A. E. Yahn, and R. T. Zook.

HISTORY OF DEVELOPMENT

Oil was discovered in the vicinity of Bradford in 1864. During that year, Job Moses completed six shallow wells along the Tunungwant Valley below Limestone in New York State about seven miles north of Bradford, which yielded small amounts of oil and gas.[3]

The first attempt to find oil within the limits of the Bradford pool itself was made in 1862, three years after the completion of the Drake well, when the old Bradford well, later called the Barnsdall well, was drilled to a depth of 200 feet with a spring pole and then abandoned.[4] This well was on the south side of West Branch on the Whitney farm near the western edge of Bradford. In the spring of 1866, the citizens of Bradford clubbed together and continued this well to a total depth of 875 feet or to within 200 feet of the Bradford sand. In 1865, F. E. Dean and brothers drilled a well to a depth of 900 feet on the Sheppard farm near the present site of Custer City, stopping about 230 feet above the Bradford sand. The Dean brothers then drilled another well on the Clark farm at Tarport, now East Bradford. Drilling was stopped at a depth of 605 feet, or over 400 feet above the top of the Bradford sand.

These early wells were drilled with the expectation of finding the oil sands of the Venango group at about the same depth as along Oil Creek in Venango County and were failures because the Venango oil sand group crops out in the Bradford district and the Bradford sands occur much lower in the geologic column. The productive sand still is referred to as the Third sand in the Bradford district as a result of this early erroneous correlation with the Third sand of the Venango district.

Early wells. The first well to reach the Bradford Third sand was drilled by James E. Butts, C. H. Foster, and Job Moses under the name of the Foster Oil Company on the Hinchey farm two miles northeast of Bradford.[5] Some oil was encountered at a depth of 751 feet and the Bradford Third sand was struck at 1110 feet in November, 1871. The daily production was

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[3] John J. McLaurin, Sketches in Crude Oil, 1896, p. 189.

[4] Chas. A. Ashburner, The Geology of McKean County: Pennsylvania Second Geol. Survey, Report of Progress R, 1880, p. 80.

[5] Chas. A. Ashburner, Idem., p. 80.

10 barrels. From that time no wells of any importance were completed until December 6, 1874, when Butts and Foster struck oil in the Butts No. 1 well on the Buchanan farm, 2½ miles northeast of Bradford. This well began with a daily production of 70 barrels and was the first well that attracted the attention of oil men to the possibilities of the district. On September 26, 1875, Frederick Crocker procured a flow of 75 barrels on the Watkins farm about one mile north of Tarport (East Bradford). This increased to 200 barrels when the well was deepened 5 feet. From then on development was rapid.

Most of the early wells were along the Tunungwant Valley in the vicinity of Foster Brook near the tracks of the branch line of the Erie Railroad which connected Bradford with the main line at Carrollton, New York, and the oil was loaded on cars direct from the wells. The Union Company completed the first pipe line and started to run oil from Bradford to Olean, New York on November 26, 1875.

During 1876, the vicinity of Tarport, now East Bradford, at the mouth of Kendall Creek was the center of excitement, with drilling extending some distance up West Branch and up East Branch as far as Degolia. Early in 1877, interest shifted to Foster Brook. Some production had also been encountered by this time at Big Shanty, seven miles south of Bradford and in the vicinity of Rock City and Four Mile, ten miles northeast of Bradford. During the spring of that year, gas was found along Indian Creek but it was not until the latter part of the summer that the oil pay beneath the gas was discovered. During June, 1877, Kendall Creek became the Mecca of the oil men and the Knapps Creek excitement started during August of that year. September saw the opening of the Quintuple tract southwest of Bradford between the East and West Branches of the Tunungwant.

Over-production. As the Bradford pool enlarged, production increased much more rapidly than the world demand. At the beginning of 1878 all available storage facilities were filled to overflowing and oil was actually running on the ground. Pipe lines refused to run more than one-fourth of the production at the prevailing prices. As a result, much oil was sold below the market price. Storage facilities were greatly enlarged and operators proceeded somewhat more cautiously with new drilling for a time.

On December 17, 1878, the Doe and Felt well at Rixford, which started at 125 barrels per day, drew the attention of oil men to the eastern margins of the pool and led to the opening of the Cole Creek district, which in 1879 became the most active scene of operations in the Bradford field.

The Tidewater pipe line from the Bradford oil field to Williamsport in Lycoming County, a distance of over 100 miles, was completed in 1879, the first oil run through the line reaching the storage tanks at Williamsport on June 4th. This was a 6-inch line. From Williamsport the oil was transported over the Reading Railroad to Philadelphia in tank cars. This was the first attempt to pipe oil to the seaboard and naturally the effort met with much opposition on the part of the railroads. After it had been completed, however, and put into successful operation, its advantages became so apparent that opposition ceased to be effective, other lines quickly followed, and within a few years oil was piped directly from Bradford to the Atlantic seaboard. The National Transit pipe line was completed to Bayonne, New Jersey in 1881. The Tidewater line was extended to Bayonne early in 1888.

Over-production continued, the large wells of the recently discovered Cole Creek district aggravating the situation so that by the middle of 1879 there was considerable agitation in favor of temporarily stopping drilling until consumption caught up with production. As has happened many times since, however, in connection with the development of new oil fields, it was practically impossible to get all the operators to agree on any program. At a meeting held in Bradford June 25, 1879, opposition to a shut-down sufficient to cause its failure was responsible for the following resolution: "Whereas, the shortest way to two dollar oil is through 25 cent oil, therefore, be it resolved, that we favor the pushing of the drill as rapidly and diligently as possible until the goal of 25 cent oil is reached." At that time, the oil market was down to 69⅜ cents.

Production continued to mount for nine years after the opening of the field by the Foster Oil Company's well until the peak was attained in September, 1880, when the average daily production reached 69,000 barrels.[6] At that time there were approximately 7,500 producing wells in the Bradford field with new wells of an average daily production of 23 barrels being completed at the rate of 460 per month.[7] 1881 was the banner year with an average daily production of 62,863 barrels and a total of 22,945,000 barrels for the year. In September of that year there were 11,200 producing wells.[8]

Decline. After 1881 a decline set in which was comparatively rapid for the first six years and then became more gradual. Although drilling slackened considerably after the peak, an appreciable extension of the boundaries of the pool occurred after that date. In the vicinity of Cyclone at the southern edge, wells with an initial production as high as 495 barrels per day were completed as late as 1884. From an annual production of 22,945,000 barrels in 1881, the output shrank until in 1888 it was only 5,300,000 barrels and in 1906, 2,000,000 barrels. Beginning about 1907 the effects of water flooding began to be noticeable in the annual production, which again commenced to rise at first slowly and then more rapidly as more and more operators adopted the water-drive. Methods of applying it improved, until, in 1935, the annual production reached 13,183,322 barrels.

Water-flooding. Although, as pointed out as early as 1880 by John F. Carll,[9] geologist of the Second Geological Survey of Pennsylvania in charge of the survey of the oil regions, water-flooding in the Venango district resulted in certain instances in the recovery of considerable additional quantities of oil, water-flooding of the haphazard and uncontrolled type, on the whole had been unsuccessful and in many cases disastrous in that district on account of the physical characteristics of the producing sands. In the Bradford field the discovery that by introducing water into one well, the production of surrounding wells could be greatly increased, was probably made accidentally. After the period of flush production of the eighties, many wells were abandoned. In some instances the casing was pulled without properly plugging the wells and in others the casing corroded and admitted fresh water from shallow horizons to the sand. In certain areas where water had thus accidentally gotten access to the sand, an increase in production in adjacent wells occurred. Just when and on what property or properties this discovery was made is not definitely known. One of the earliest floods is reported to have started two miles southeast of Rew in the Cole Creek district, and another, one mile northeast of Aiken. In both these areas so-called "loose streaks" are present in the sand which would make the effects of water-flooding more quickly noticeable. As soon as the cause of this increase was understood, water-flooding began to be practiced secretly by some of the operators.

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[6] John F. Carll, Seventh report on the oil and gas fields of western Pennsylvania for 1887, 1888: Pennsylvania Second Geol. Survey, Report I-5, 1890. Statistical Chart No. 3.

[7] Chas. A. Ashburner, op. cit., Plate XV.

[8] John F. Carll, op. cit., Statistical Chart No. 3 and pages 40-41.

[9] John F. Carll, The Geology of the Oil Regions of Warren, Venango, Clarion, and Butler Counties; Pennsylvania Second Geol. Survey, Report III, 1880, p. 263.

Circle flood. Intentional water-flooding probably was practiced on a small scale in the early nineties. For a long time floods were started by simply shooting, cutting, or pulling the casing in an oil well which was no longer profitable to operate and letting the water in on the producing sand. It was found that in many instances neighboring wells were benefited by the resulting water-drive. Additional wells were usually drilled around the area of advancing water as the old wells were spaced too far apart for efficient flooding. Later it was discovered that much better results could be obtained by tubing the water intake wells, as otherwise they soon became filled with silt and cavings from the walls to a level above that of the sand, thereby preventing access of the water to the sand. This method of applying the water-drive came to be known as the "circle" type of flood.

It was not until 1907 that the effects of flooding became noticeable in the annual production of the field which, up to that time had been gradually declining, following the period of flush production in the early eighties. For a long time many of the operators did not approve of introducing water into the sand and most of the larger companies opposed it. Those who engaged in the practice did so more or less secretly, as the Pennsylvania law, until 1921, required that all abandoned wells and dry holes be plugged in such a way as to prevent water entering the oil and gas sands. This law was construed to prohibit flooding. In 1921, the Pennsylvania legislature passed a special act legalizing the practice when applied to the Bradford sand.[10]

Line flood. The great extension of water-flooding which followed the passage of this Act brought the petroleum engineers and geologists into the field. The methods of applying the water-drive underwent rapid improvement. The old "circle" flood, as generally developed in the Bradford field, had always been a more or less haphazard operation. Realizing this, the Forest Oil Company in 1922 started what came to be known as the "line" flood. This consisted of two rows of oil wells staggered on both sides of an equally spaced line of water intake wells extending across a property. In this type of flood, the wells in the rows were spaced from 200 to 220 feet apart and the rows 100 to 130 feet. When a row of oil wells had about reached its economic limit of production, which usually happened within two or three years, another row of staggered wells was drilled outside of it. The wells of the former were then converted into water intakes. The "line" flood, with various modifications to suit individual property conditions, came to be generally adopted throughout the Bradford field until in 1928 it in turn was superseded by the still more intensive method known as the "five-spot," which is now employed on practically all new development work.

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[10] No. 322. An act to regulate the drilling, operating, and abandoning of oil and gas wells, and providing a penalty for violations of this Act. Approved May 17, 1921. Laws of the General Assembly of the Commonwealth of Pennsylvania passed at the Session of 1921, pages 912-915.

Five-spot method. In the "five-spot" method, the whole tract that is to be developed is laid out in a pattern of squares. Water intake wells are placed at the corners of the squares and producing wells at their centers. The first "five-spot" operation in the Bradford field was attempted by the Associated Producers Company on a property in the southern part of the field as early as 1924. Frank Haskell was responsible for the idea. Unfortunately, the water intake wells were spaced 500 feet apart. This proved to be too great a distance to give any appreciable results, as a core taken in the area since has shown that the sand is fairly tight and, therefore, requires closer spacing. In cleaning out the water intake wells later to find out what was wrong, it was also discovered that they had not been tubed properly and that silt had accumulated in the bottom, effectually sealing off the sand. It was, therefore, not until late in 1927 and early in 1928, when the "five-spot" development undertaken by Arthur E. Yahn of Olean on the Kuno Kuhn property near the head of Oil Valley in the northern part of the field, commenced to show results, that the possibilities of the method were realized. Since that time, its use has spread widely.

Pressure flood. A further development associated with the introduction of the "five-spot" method of flooding has been the application of additional hydraulic pressure to that of the hydrostatic head of the column of water in the intake well. This is accomplished by introducing the water under pressure at the top of the well by means of pumps. While this had already been tried out as far back as 1925 and 1926 in both the Richburg and Bradford pools with rather promising results, the old style flooding methods were not particularly well suited to its use and these experiments, therefore, did not attract much attention until 1928 when John Messer of Bolivar, New York, realizing the ideal conditions that the "five-spot" flood afforded for the application of additional pressure, tried it out on a property in the Richburg pool that the Messer Oil Company was at that time developing. The early results were so satisfactory that the introduction of subsurface water into intake wells has now become almost obsolete so far as new development work is concerned. The wells are tubed to take water from the surface only and usually in such a manner that 400 to 1200 pounds pressure, and in some instances more, per square inch at the top of the well can be applied. This type of flooding has come to be known as the "pressure" flood.

Cores. On account of the large immediate investment of capital involved in the development of a property under the modern system of flooding, more exact knowledge of the character of the producing sand became essential in order to determine whether the expenditures were warranted on any particular tract and what method of procedure should be adopted. It has, therefore, become common practice in recent years to take cores of the sand in connection with new development work. The Northwestern Pennsylvania Oil Producers Association took the first core of the Bradford sand from a well half a mile west of Custer City during the latter part of the summer of 1924, using a diamond drill. On account of the expense of taking cores with a diamond drill, no further coring was done until the spring of 1928 when core drilling with cable-tools was introduced by the Sloan and Zook

Company. Since that time, hundreds of cores of the Bradford sand have been taken.

Renewed drilling. The striking results obtained by the newer flooding methods as contrasted with the older practice, led to an intensive drilling campaign which reached a climax during 1929 when, according to figures compiled by the Oil and Gas Journal, 2,679 new wells were completed in the Bradford field.[11]

While no doubt the price of $4.35 per barrel received during the first half of 1929 attracted the large sums of additional capital required for the new work, the discovery that the more intensive methods of water-flooding resulted not only in a much quicker return of the capital invested but also, in many instances, in a greater recovery per acre, was probably an even more important factor. Production jumped from 6,362,000 barrels in 1928 to 9,334,000 barrels in 1930, in spite of the fact that during the last half of 1930, a curtailment program was in operation.

Early in 1930 it became apparent that this feverish activity had been ill-advised. At the beginning of 1929 no indications of the coming of a major business and industrial depression, such as set in during the fall of that year, had as yet appeared on the horizon. The East Texas field, which two years later poured out such floods of oil as to demoralize the entire petroleum industry, had not been discovered. Thoughtful observers could not help feeling that the production of the Bradford field was being increased more rapidly than the refiners of Pennsylvania-grade crude oil were developing additional markets for their products, and that a drop in price was inevitable. Although in 1929 the average price for the entire year had been $3.95, in 1930 this had declined to $2.59, in 1931 to $2.02, in 1932 to $1.88, and in 1933 to $1.86.

Curtailment. By May 1930 it was realized that some action would have to be taken to slow down production. A notable decline in drilling had already taken place. A voluntary curtailment program was inaugurated on May 16 under the supervision of a Conservation Board, which called for a 20 percent reduction in production based on April figures. On July 1st this was increased to 50 percent. The Conservation Board functioned as a prorationing body until October 15, 1931 when new contracts were entered into with the producers by the major pipe line companies serving the district, which permit the latter to determine the percent of the base amount stipulated that they will run. On the whole, the voluntary curtailment program met with a hearty response from most of the producers so that the 1931 production dropped to 8,812,000 barrels. During the summer of 1932, only 158 drilling rigs were active in the Bradford field as compared with 588 during 1929. With an increasing demand for Pennsylvania-grade crude oil and the accompanying rise in price, the rate of drilling again increased during 1933 and 1934.

The advantages of operating under the intensive methods of water-flood now in use can be fully realized only if a tract which has been developed under this system can be allowed to produce to its full capacity. This means that the output of the entire field must be adjusted to the demand by planning wisely the amount of new development work undertaken each year.

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[11] Oil and Gas Journal, January 30, 1930, p. 279.

This can be accomplished only by the concerted action of all the producers in the field.

TOPOGRAPHY

Drainage

The streams which drain the Bradford district are all tributaries of Allegheny River. This river, which has its headwaters in Potter County to the east, flows in a huge semicircle around the Bradford field but nowhere touches the field proper. In the Bradford area its largest tributary is Tunungwant Creek which cuts across the entire length of the field from south to north. This creek and its tributaries drain the western half of the district. The streams of the southeastern part of the field flow into Marvin Creek, another tributary of Allegheny River, and in the northeastern part, directly into the Allegheny. A small part of the southern end of the Bradford field drains into Kinzua Creek which also flows into Allegheny River.

A drainage pattern of the Bradford area resembles the branches of a tree; it is of the dendritic type characteristic of regions underlain by nearly horizontal sedimentary rocks. The structure of the underlying strata is such that it has had only a minor influence upon the drainage pattern. An examination of Plate C reveals that jointing has been more important than folding in this respect.

Several drainage features are of interest. One of these is the great arc of Allegheny River around the area. Another is furnished by Kinzua and Tunungwant Creeks. The headwaters of these two streams are only about half a mile apart. Kinzua Creek is only 29 miles long. It joins Allegheny River at the village of Kinzua. Tunungwant Creek, flowing north for 20 miles, enters the Allegheny at Riverside Junction in New York State. From Riverside Junction to Kinzua, the distance via the river is 37 miles. In other words, water entering Tunungwant Creek in the vicinity of Bingham and Simpson has to travel nearly twice as far as water entering Kinzua Creek in that vicinity, in order to reach the same point opposite the mouth of Kinzua Creek. The above features will be discussed under Historical Geology.

Relief.

The Bradford district is one of comparatively rugged topography, with maximum differences in elevation of nearly 1,000 feet. Most of the area is wooded. Only the broad valley floors, a small portion of the immediately adjacent slopes along the lower portion of the major streams and relatively small tracts on the upland area in the southern part, are cleared. These cleared areas are in farms. All the original pine and hemlock forest which once covered the area was removed years ago by the lumber men, but a fine stand of hardwood, chiefly maple, beech, birch, and gum trees, has sprung up in those places where growth has not been interfered with by the activities of the wood chemical manufacturer. The latter industry flourished in the Bradford region until a few years ago and consumed large quantities of hardwood annually, so that over extensive areas the trees are small. Fortunately, the Bradford region has suffered less from destructive forest fires than many other parts of northern Pennsylvania, due largely to the vigilance of the oil producers of the region.

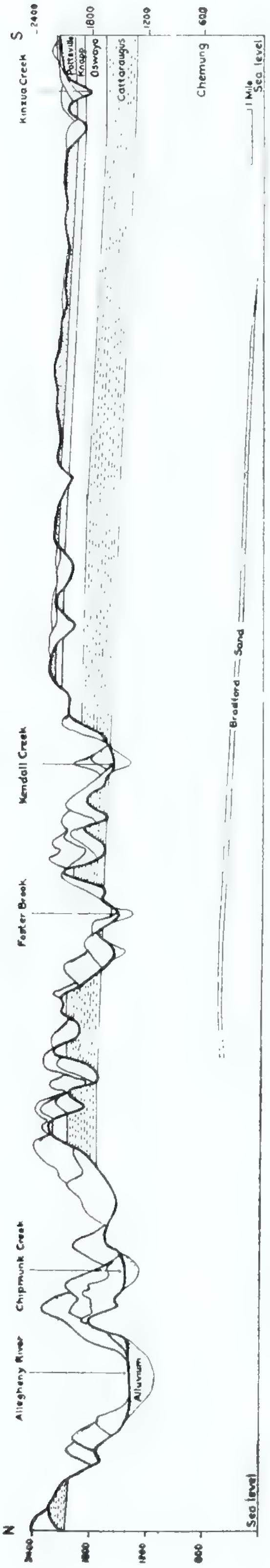
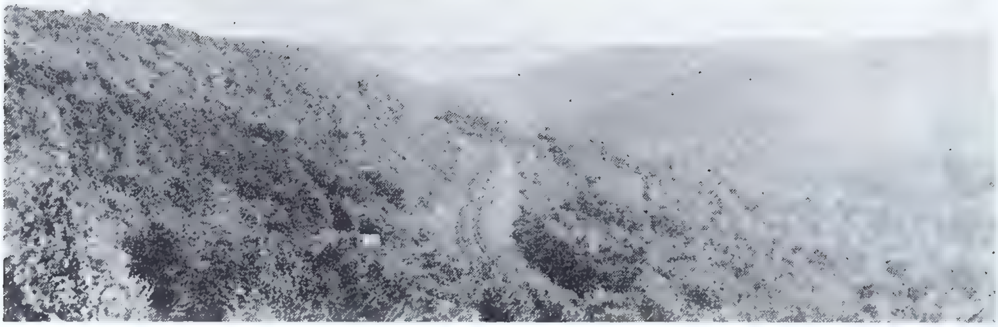
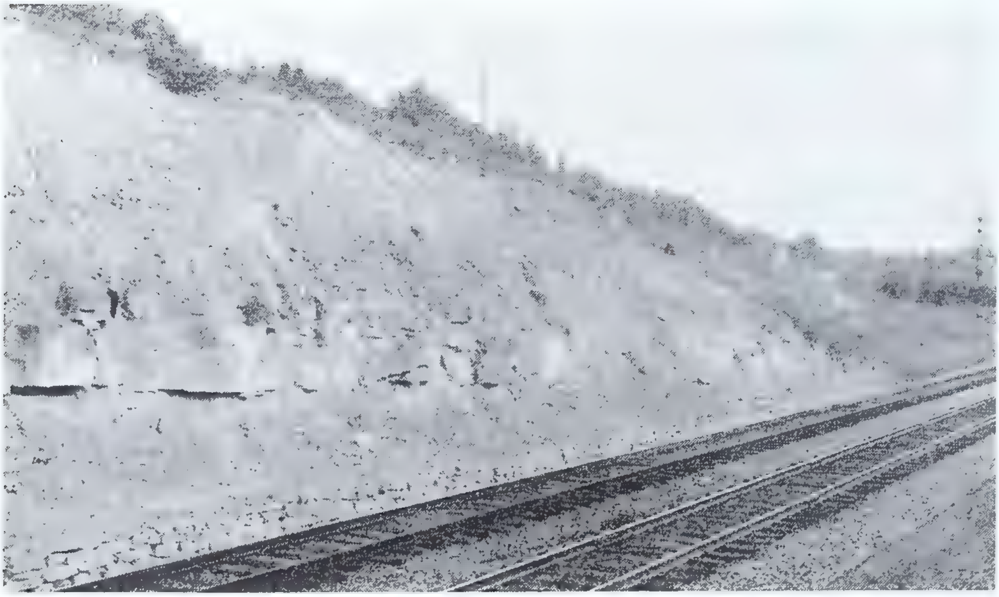


FIGURE 2. Four projected profiles and geologic structure section in the Bradford district.



A. View looking up East Branch from hill above Dent across dissected surface of Schooley peneplane.

B. View looking west from Rock City across dissected surface of Schooley peneplane.



C. Hayfield shales and sandstone 3,200 feet north of Bingham Station.

In spite of the fact that steep slopes are common, good outcrops of bedrock are scarce. This is because the outcropping strata consist largely of shale which, under the humid climatic conditions, weathers readily into a soil that supports a dense vegetation. Sandstones and conglomerates are common only in the highest hills. The formations can be examined to best advantage along highway and railroad cuts and in the few quarries which have been opened in the region.

There is a rather marked contrast in the topography of the northern and southern parts of the Bradford region. In the northern part which is nearer Allegheny River, the master stream of the region, erosion has reached the mature stage. The divides are narrow, valley sides are steep, and the valley floors narrow except along the lower stretches of the major streams where deposition in comparatively recent geologic time has developed flats nearly a mile wide in places. In the southern part, on the other hand, comparatively large areas of gently undulating upland still remain, into which the present streams have incised steep-walled narrow gorges.

Peneplanation.

Although the region is one of rugged topography, when a broad expanse is viewed from the crest of one of the higher hills or ridges the surface irregularities become less conspicuous. The skyline appears as a straight and nearly level line. The hill and ridge tops rise to a common level and appear to merge in the distance, as shown in A and B of Plate 2. If the valleys were filled to the level of the divides, the surface of the area would become a gently undulating plain with an elevation of approximately 2400 feet at the north and 2200 feet at the south.

In Figure 2 is shown the relationship of the underground structure to the old surface into which the present streams have cut their valleys. It will be noticed that the dip of the strata is somewhat greater than that of the present upland surface. The ancient surface bevels the outcrops of successively lower formations to the north and hence represents an old erosion surface or peneplane which has been elevated, warped and tilted slightly, and subsequently dissected by stream erosion. This old erosion surface has been correlated with the Schooley peneplane.[12] Remnants of this surface, only moderately reduced below the original level, still remain over considerable areas in central and northern Pennsylvania and adjacent parts of south-central New York.

Bottom Lands

Among the notable topographic features of the Bradford region are the flats, up to one-half to three-fourths of a mile wide, along the lower portions of all the major valleys. These terminate headward at elevations between 1600 and 1700 feet. The flats are underlain by unconsolidated alluvium, in some places reaching maximum depths of 250 feet, which was deposited during Pleistocene glaciation. Since Pleistocene time the streams have cut their present channels to only shallow depths, frequently not much more than five feet, into the alluvial deposits forming the flat floors.

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[12] George H. Ashley, The Scenery of Pennsylvania: Pennsylvania Topographic and Geologic Survey, Bull. G 6, 1933, p. 19.

GEOLOGY

For proper conception of the mode of occurrence of petroleum and natural gas in the Bradford district, a knowledge of the geology of the region as a whole is essential. A description of the rocks which underlie the region, both those which can be examined at the surface and those whose presence has been revealed by the drill, is, therefore, included under the heading of stratigraphy. Their relations to one another and to the surface are discussed under structural geology. Finally, the series of events which led to the development of the present geological features are described under historical geology.

For the purpose of dating events in geological history, geologic time has been divided into major time units called eras. These are further subdivided into periods. The periods, in turn, are divided into still smaller time intervals called epochs. All the strata deposited during a single period in geologic time constitute a system; and during a single epoch, a series. The term "formation" is, in general, applied to the smallest units that can be shown on a geologic map. A formation may consist of a single succession of like sediments, such as sandstone, shale, or limestone, or a succession or alternation of sediments that are unlike but contain closely related fossil faunas or floras. A formation may be further subdivided into members and lentils. Several formations may be assembled into a group. In general, a series consists of more than one formation and several series constitute a system.

Since living organisms first appeared upon the earth, there has been a progressive evolution from the structurally simple to the more complex. The record of the various successions of plants and animals has been preserved in the sediments in which their remains became entombed, in the form of fossils. The unravelling of this record has been the task of the geologist and paleontologist. The relative time of appearance and disappearance of a sufficiently large number of forms of plant and animal life with respect to the geologic time scale is now known to enable the geologist and paleontologist, in most instances, to determine the proper position of a particular stratum in the geologic column or time scale from the fossils which it may contain.

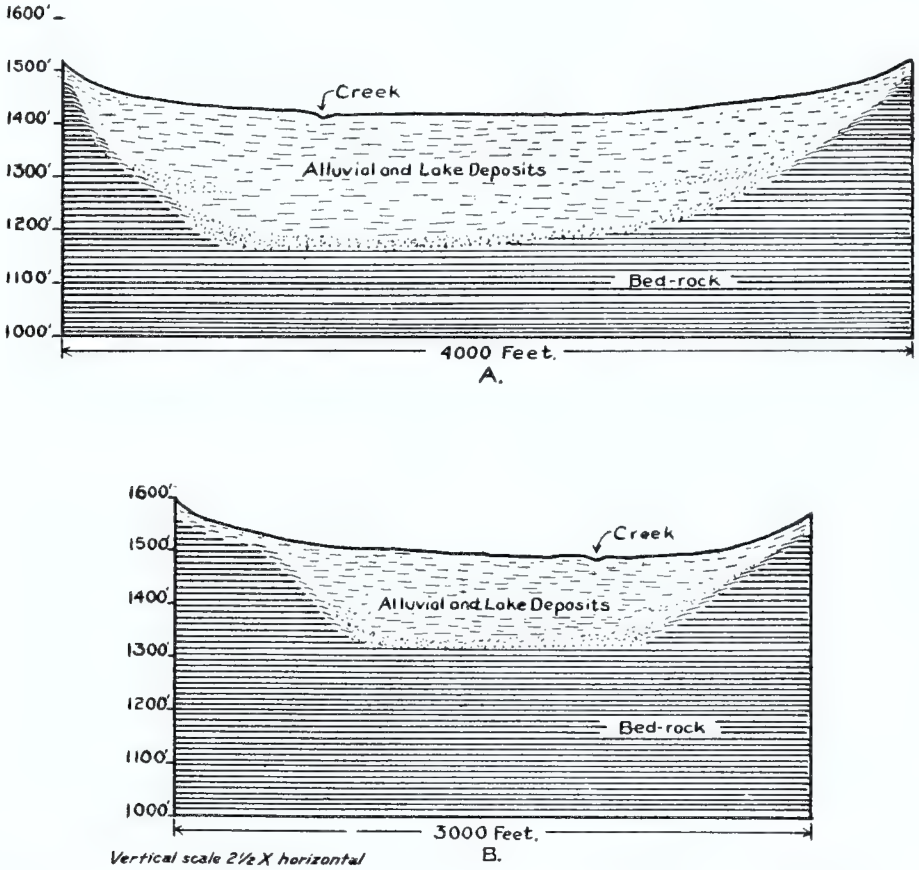
For the benefit of those who are not familiar with the geological time table, the succession of eras and periods with the youngest at the top and the oldest at the bottom is shown in Table I.

Table I. Geological Eras and Periods.

Eras	**Periods**
Cenozoic	Quaternary
	Tertiary
Mesozoic	Cretaceous
	Jurassic
	Triassic
Paleozoic	Permian
	Pennsylvanian or Upper Carboniferous
	Mississippian or Lower Carboniferous
	Devonian
	Silurian
	Ordovician
	Cambrian
Proterozoic	
Archeozoic	

STRATIGRAPHY

In addition to the unconsolidated alluvial and lake deposits of Quaternary age along the lower portions of the major valleys of the Bradford district, somewhat more than 1,000 feet of consolidated strata appear at the surface within the limits of the district, ranging in age from lower Pennsylvanian to upper Devonian in descending order. Nearly 6,000 feet more have been explored with the drill. The deepest well in the district reached strata of upper Ordovician age.



Vertical scale 2½ X horizontal

FIGURE 3. A. Cross-section of Tunungwant Valley below Foster Brook; B. Cross-section of East Branch of Tunungwant Valley above Custer City.

SURFACE FORMATIONS

The formations appearing at the surface in the Bradford district consist of unconsolidated sediments of Quaternary age and consolidated or bedrock formations ranging in age from lower Pennsylvanain to upper Devonian. The outcrops of these formations over that portion of the Bradford district included in the Bradford quadrangle are shown on Plate B.

QUATERNARY SYSTEM

The lower parts of the major valleys of the Bradford district are filled with unconsolidated sediments which, in the Tunungwant Valley below Foster

Brook, extend to a depth of nearly 250 feet. The thickness of these deposits gradually diminishes headward and they become relatively insignificant at elevations of approximately 1700 feet along most of the streams. A cross-section of the Tunungwant Valley below the mouth of Foster Brook is shown in Figure 3-A, and a similar cross-section of the valley of the East Branch of Tunungwant Creek above Custer City, in Figure 3-B. In each case, the profile of the bedrock shows the shape of the former valley. The depth to which the old valley has been buried is indicated by the profile of the present surface. These cross-sections were constructed from data furnished by records of numerous oil wells nearby. At Foster Brook the surface of the valley has an altitude of 1418 feet, and the buried channel 1170 feet. At Custer City the altitude of the surface is 1490 feet, and the buried channel 1312 feet. The two cross-sections are six miles apart, making the average slope of the unconsolidated deposits 12 feet per mile as contrasted with 24 feet for the buried channel. The unconsolidated deposits thin from 248 to 178 feet in the six miles.

The unconsolidated deposits underlying the bottom lands of the major valleys were laid down largely during the Pleistocene epoch of the Quaternary period. The glacier which occupied the northern half of the North American continent at that time, extended as far south as Salamanca, New York. The Allegheny River was not able to carry away all the debris which was dumped into it by the melting ice and commenced to fill its valley with sand and gravel, thereby building up its flood plain to the level of the present high terraces which occur at an altitude of 1480 to 1500 feet.[13] As a result its tributaries became blocked. At first they deposited small quantities of sand and gravel in their channels but since their loads of debris were small as compared with those dumped into the Allegheny by the glacier, they could not build up their beds as fast as the Allegheny and consequently were flooded and became lakes. The lake which occupied the valley of the Tunungwant and its tributaries at the maximum stage probably reached a level corresponding about to the position of the present 1500-foot contour.

The streams deposited gravel, sand, and silt in the lakes, the coarser sediments near shore and the finer over the middle portions until the lake basins were nearly filled when the waters again commenced to recede. Although the lake waters probably did not rise above the 1500-foot contour, deposition continued upstream to altitudes of 1700 feet or more as the streams adjusted themselves to the new gradient imposed upon them by the lakes. In general, the alluvial deposits laid down above 1500 feet are coarser than those deposited in the lakes.

The materials comprising the unconsolidated deposits are of local origin. They are the disintegration and decomposition products formed by the weathering process from outcropping formations and were transported to their present positions by the streams of the region. In recent years, these deposits have become of considerable economic importance because much of the water used for flooding purposes is now obtained from them.

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[13] A. K. Lobeck, A popular guide to the geology and physiography of Allegany State Park; New York State Museum Handbook 1, 1927, pp. 96-112.

PENNSYLVANIAN SYSTEM

POTTSVILLE SERIES

The youngest bedrock in the Bradford district belongs to the Pottsville series of the Pennsylvania system. The principal area occurs in the southern part of the Bradford quadrangle where the broad plateau between the headwaters of Tunungwant and Kinzua Creeks is immediately underlain by rocks of Pottsville age. Pottsville strata also cap most of the high hills in the northwestern part of the quadrangle but are absent in the northeastern. Small patches have escaped erosion along the high ridge in the vicinity of Harrisburg, Rock City, Fourmile, and Flatiron just beyond the northeastern limits of the quadrangle in New York State and at the head of Windfall Creek in Pennsylvania.

In northwestern Pennsylvania the Pottsville series is represented by the following members in descending order: Homewood sandstone, Mercer shale and coal, Connoquenessing sandstone, Sharon shale and coal, Olean conglomerate.

The highest member, the Homewood sandstone, was not observed within the limits of the Bradford quadrangle. If it is actually present underneath some of the higher knolls of the plateau in the southern part of the quadrangle, its outcrops are not sufficiently conspicuous to be readily recognizable. Ashburner[14] correlated the coal bed at one time worked in the old Davis mine, southwest of Lafayette cross-roads, shown at locality 21 on the map of Plate C, with the Clermont (Clarion bed) which occurs above the Homewood in the lower part of the Allegheny formation, but the writer was not able to verify this correlation. Ashburner gives an interval of 200 feet between the bottom of this bed and the base of the Olean. The writer found this interval to be only 137 feet, which makes the horizon correspond rather closely with that of the Alton coals which were formerly mined southeast of Mount Alton. These are part of the Mercer member.

The Olean conglomerate, the basal member of the Pottsville in the Bradford district, rests unconformably upon the Knapp formation. The old erosion surface upon which the Olean was deposited was irregular. As a result, the base of the Olean is sometimes found 20 to 60 feet lower than a nearby outcrop of the Knapp. This can be observed on Mount Raub and Hawkins Hill southeast of Bradford and also along the ridge near Harrisburg, New York. Near the head of Hedgehog Hollow, 3 miles northwest of Bradford, the base of the Olean occurs 66 feet above the base of the Knapp conglomerate, but at the head of Niles Hollow, 3 miles southwest of Bradford, this interval is only 13 feet, and in the vicinity of Tallyho in the southwestern corner of the quadrangle, it is 195 feet.

MERCER SHALE AND COAL

The Mercer shale and coal is the highest member of the Pottsville that was definitely recognized in the area covered by the Bradford quadrangle. Coal beds belonging to this horizon were at one time mined on a small scale southeast of Mount Alton at localities 18, 22, 23, and 24 on the map shown in Plate C; southwest of Lafayette cross-roads at locality 21; and at Irishtown at locality 25. The small coal basin southeast of Mount Alton occurs along the Ormsby syncline; the abandoned mines southwest of Lafayette cross-roads and at Irishtown are on the southeastern limb of the Big Shanty syncline.

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[14] C. A. Ashburner, The geology of McKean County: Pennsylvania Second Geol. Survey, Report R, 1880, pp. 188-189.

The following columnar section, showing the character of the Mercer member, was compiled along the wagon road and the Erie Railroad northwest of Kinzua viaduct in the vicinity of locality 18 on Plate C:—

Mercer member near Kinzua viaduct

		Feet
Gray fissile shale with some clay ironstone concretions		6.00
Black fissile carbonaceous shale		1.50
Dark gray shale		.50
Coal (possibly Upper Alton of Ashburner)		1.00
Light gray clay with abundant plant remains		2.50
Gray, thin bedded, sandy shale and shaly sandstone		5.00
Gray, fine-grained, thin bedded shaly sandstone (cross-bedded)		3.00
Bluish-gray fissile shale		6.00
Covered		19.00
Coal (top not exposed)	Middle Alton of Ashburner	.13
Clay		.03
Coal		.06
Clay		.03
Bony coal		.50
Clay		3.60
Coal (bottom not exposed)		.70
		49.55

The bottom of the Mercer member was not exposed at this locality. The base of the above section lies approximately 35 feet above the base of the Connoquenessing sandstone (Kinzua Creek of Ashburner) and 122 feet above the base of the Olean. The section is shown in graphic form under locality 18, Plate 3.

Ashburner[15] gives the following record of a drill hole bored in the above vicinity:

Log of well near Kinzua viaduct

		Ft.	in.
Detritus		3	6
Fire clay		1	3
Nodular iron ore		1	3
Coal		2	4
Fire clay		0	8
Coal	Middle Alton	0	6
Slate		0	2
Coal		1	0
Slate		0	10
Coal		1	4
Black shale		8	0
Fire clay		3	0
Coal	Lower Alton	0	4
Fire clay		3	6
Coal		1	3
Fire clay		1	0
White sandstone		6	6
Dark blue slate		3	9
Indurated fire clay		3	9
Brown and olive sandstone		41	0

The base of the fire clay underneath the Lower Alton coal probably marks the base of the Mercer in this section.

Ashburner[16] applied the name Alton coal group to the Mercer member of the Pottsville because the coal which was being mined southeast of Mount Alton during the late seventies occurs at this horizon. He recognized that these beds occupy the same stratigraphic position in the Pottsville series as the Mercer. The following two sections of the Middle Alton bed were measured by him in different parts of the Longwood Coal Company's mine at Bond Vein, three-fourths of a mile southeast of Mount Alton, locality 24 on Plate C, operated by James E. Butts.[17]

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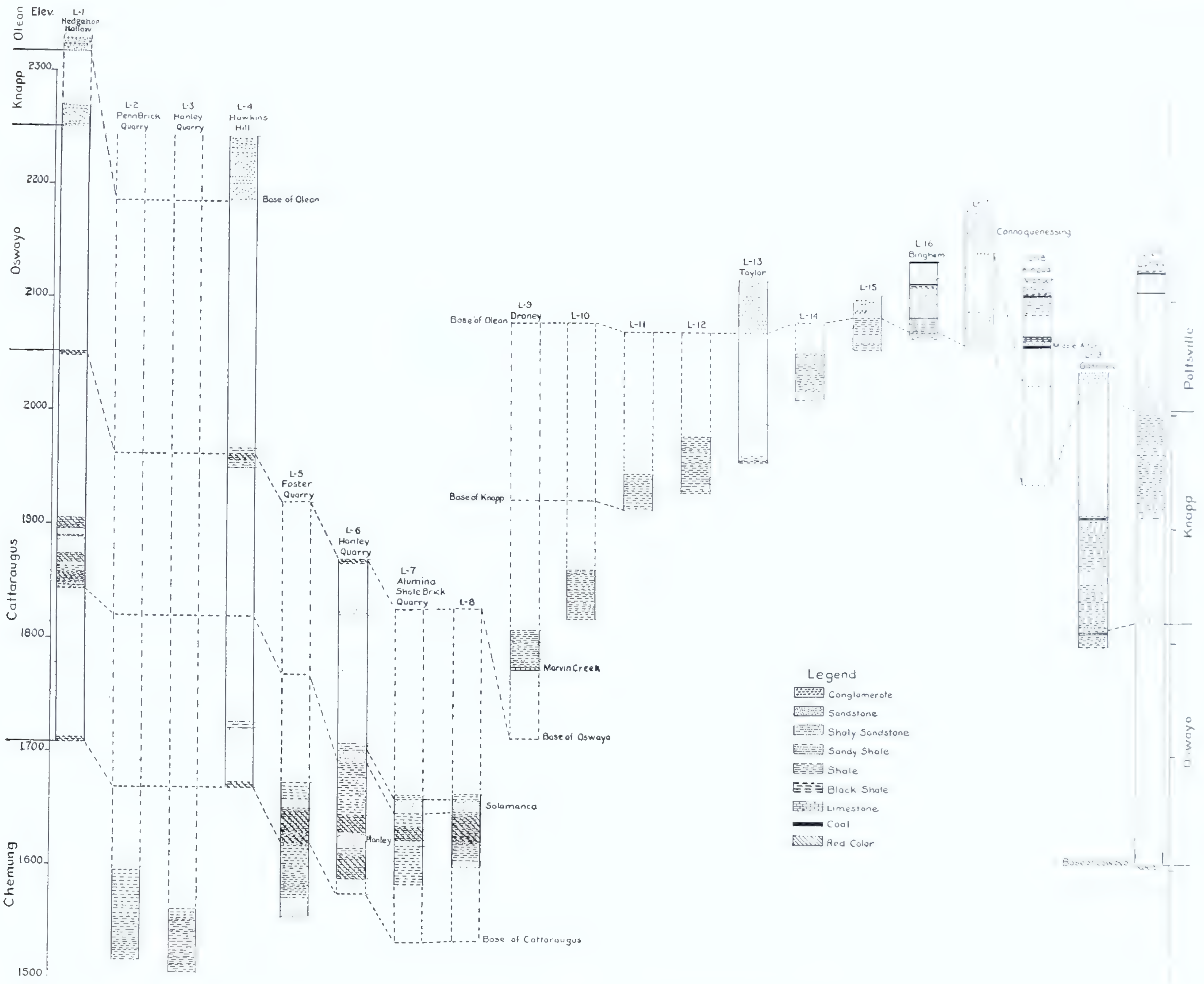
[15] C. A. Ashburner, op. cit., p. 204.

[16] C. A. Ashburner, op. cit., pp. 51-52.

[17] C. A. Ashburner, op. cit., pp. 195-197.



Columnar sections measured in the Bradford quadrangle.

Sections of Middle Alton coal bed.

Shale roof good	Ft.	in.
Coal	1	9
Slate	0	2
Coal	1	0
Slate and coal	0	8
Sandstone	1	4
Coal	1	6
Fire clay		

Rock roof good	Ft.	in.
Coal (bony)	0	8
Coal	1	9
Fire clay	0	0
Soft coal	1	5
Black slate	0	6
Coal	1	2
Hard sandy fire clay	1	6
Coarse white sandstone		

Analyses of the three benches of coal made by A. S. McCreath showed the following composition:

	Top bench	Middle bench	Lower bench
Water at 225° F	.670	1.030	.710
Volatile matter	36.065	37.630	32.980
Fixed carbon	48.417	51.237	46.867
Ash	13.790	8.550	16.500
Sulphur	1.058	1.553	2.943

Very little coal is being mined within the limits of the Bradford quadrangle in 1935. During and just after the World War, a small quantity was obtained from a stripping operation half a mile northwest of Kinzua viaduct at locality 18, Plate C, and a little "crop coal" was mined at the site of the old Davis mine west of Lafayette cross-roads at locality 21. Both stripping and underground mining on a small scale were revived in 1933 by the Erich Coal Company at the same localities. The coal is delivered to Bradford, Olean, Salamanca, and other nearby points by trucks.

During the summer of 1934, only the workings at Lafayette cross-roads were accessible. The bed occurs in the Mercer member of the Pottsville. In a room off the main entry about 400 feet from the outcrop the following section was measured:—

	Ft.	in.	
Gray shale roof			
Coal	0	5	
Pyrite seam	0	1	(omitted from sample)
Coal high in pyrite	0	8	
Carbonaceous shale	0	1	(omitted from sample)
Coal	1	2	
Carbonaceous shale	0	2	(omitted from sample)
Coal	2	5	
Gray shale floor			

A sample taken at this point was submitted to the Pittsburgh Station of the U. S. Bureau of Mines for analysis. The results were as follows:—

Proximate analysis (air dried)	Percent	Ultimate analysis (air dried)	Percent
Moisture	1.4	Hydrogen	4.5
Volatile matter	33.2	Carbon	60.6
Fixed carbon	44.7	Nitrogen	1.1
Ash	20.7	Oxygen	4.8
Sulphur	8.3	Sulphur	8.3
Air-drying loss	1.6	Ash	20.7

Calorific value: Calories, 6,339; British thermal units, 11,410; softening temperature of ash, 2190° F.

Prospecting by the Erich Coal Company during 1934 along the divide between Turnup and Thundershower Runs, 1½ miles southwest of Timbuck, failed to find a bed of workable thickness. Conditions were better for the study of the coal beds when Ashburner made his survey of McKean County than they are at present. There was a live interest in the coals of the county at the time and numerous openings existed that could be examined. Ashburner[18] summarized his findings as follows:—

> "The Alton coal beds have an extremely variable character. It is a noticeable fact that never has but one of the beds been worked in any one locality. The upper bed has never been mined except at the new mines of the Buffalo Coal Company on Instanter Creek. (This locality is outside the Bradford quadrangle.) The middle bed has been intensively worked at Alton and is at present being mined by Mr. James E. Butts. The lower bed has been opened but has never been worked."

CONNOQUENESSING SANDSTONE

The Connoquenessing sandstone member of the Pottsville is well developed in the southern part of the Bradford quadrangle. Ashburner[19] called this sandstone the Kinzua Creek on account of the fact that it forms the rimrock along the valley occupied by that creek. He correlated it with the Upper and Lower Connoquenessing sandstones of northwestern Pennsylvania. Outcrops of this sandstone are common, but rarely is the entire thickness exposed.

The Connoquenessing sandstone in the Bradford region consists largely of a coarse-grained, nearly pure quartz sandstone. Conglomeritic layers are present in it at some localities. The pebbles consist almost entirely of quartz but, as a rule, are smaller and less abundant than those in the underlying Olean. They also are less rounded than the pebbles in the Olean. On the whole, however, there is a marked resemblance between the Connoquenessing and certain phases of the Olean. Considerable care not to confuse the two has to be exercised in the field.

A good exposure of the Connoquenessing sandstone occurs in the cut along the Buffalo, Rochester, and Pittsburgh Railroad, 1.8 miles southeast of Backus, at locality 17, Plate C. The following section was measured at this point:—

Light gray, coarse, massive quartz sandstone, in part cross-bedded. (Conglomeritic layers with small angular to subangular quartz pebbles up to 10 millimeters in diameter occur near the top and middle.)	38.0 feet
Covered	49.0 feet
Olean conglomerate and sandstone	32.5 feet

The appearance of the Connoquenessing sandstone in this outcrop is shown in Plate 4-A.

At the above locality, the interval between the base of the Connoquenessing and the base of the Olean is 82 feet. At the head of McQuen Run north of Ormsby it is 73 feet; on the west side of Thundershower Run, 2½ miles above its mouth in the southwestern part of the quadrangle, 91 feet; and at the head of the West Branch of Tunungwant Creek on the south side, 75 feet.

SHARON SHALE AND COAL

Very few exposures of the rocks between the base of the Connoquenessing sandstone and the top of the Olean conglomerate occur in the Bradford quadrangle. At no place was a complete section found. The interval is occupied chiefly by shales. At several localities a thin bed of coal was seen at this horizon. This coal crops out in the cut 1,300 feet south of Bingham

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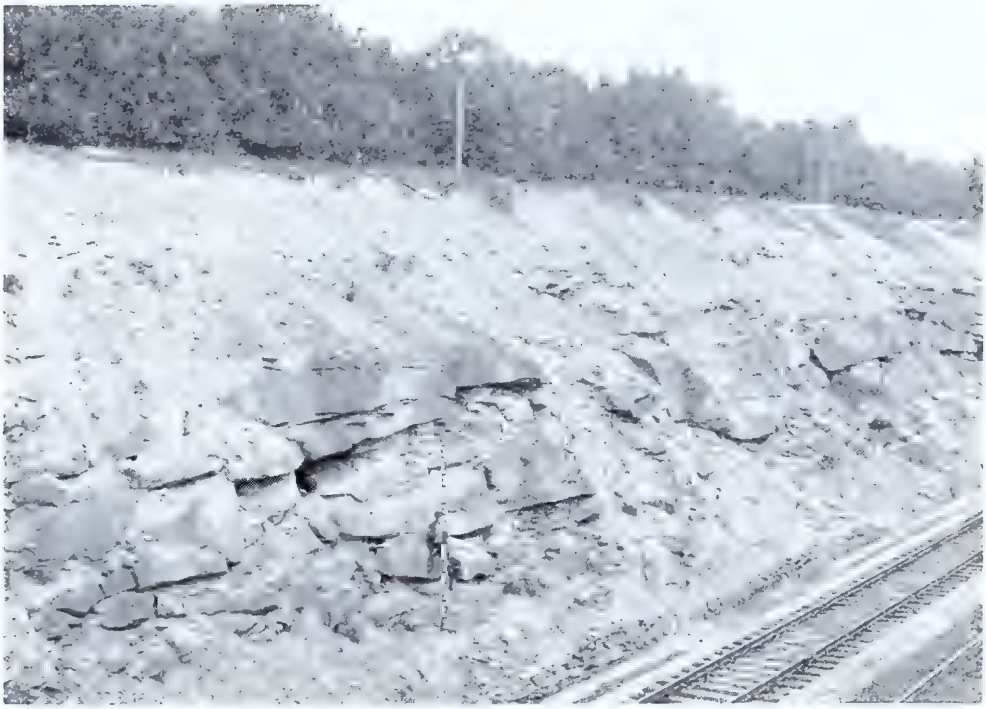
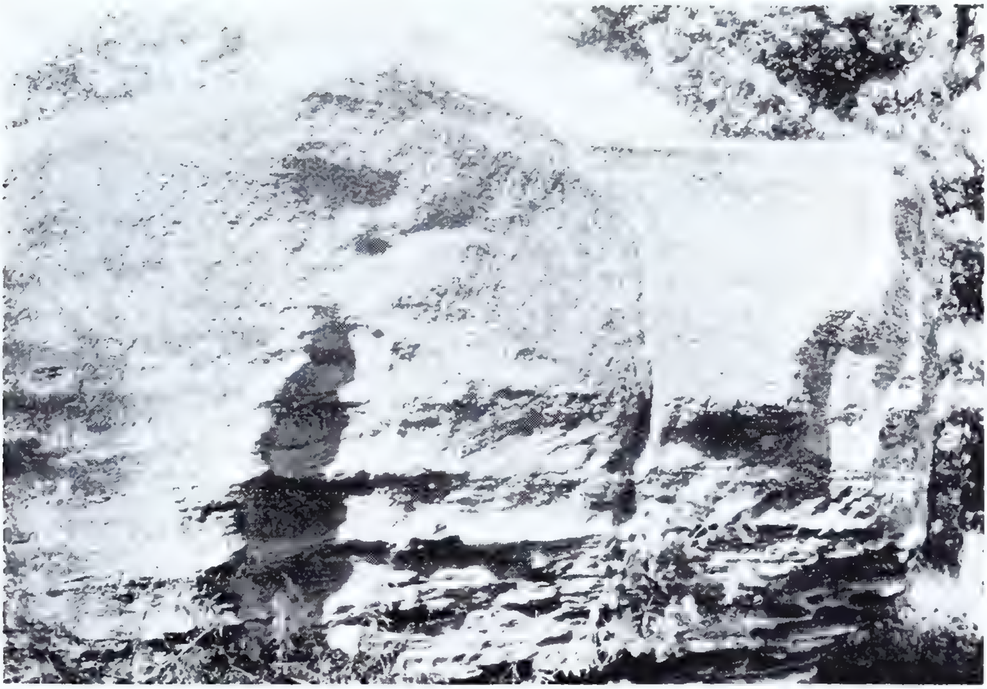
[18] C. A. Ashburner, op. cit., pp. 82-84.
[19] C. A. Ashburner, op. cit., pp. 54-55.

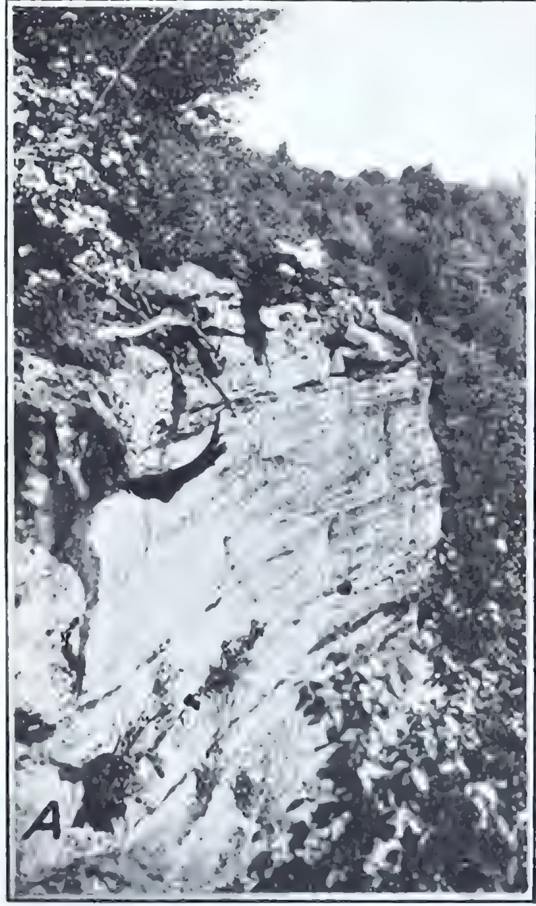


A. Connoquenessing sandstone in railroad cut 1.8 miles southwest of Backus.



B. Olean conglomerate at Flatiron Rock, Cattaraugus County, N. Y.

PLATE 5



Oleon conglomerate west of Hazelton Mills, near head of West Branch.

Lower Knapp conglomerate north of Tallyho.

Lower part of Knapp formation exposed in quarry of Kushequa Brick Company at Gaffney.

Station along the Buffalo, Rochester and Pittsburgh Railroad. Its position with respect to the top of the Olean, is shown in the section marked locality 16 on Plate 3.

Ashburner[20] called the coal between the Connoquenessing and Olean, the Upper Marshburg. It was once opened up southwest of Marshburg where it consists of 2½ feet of shaly cannel coal unfit for use as a fuel. It is not likely that this coal possesses a workable thickness anywhere in the Bradford quadrangle.

OLEAN CONGLOMERATE

The Olean conglomerate is the basal member of the Pottsville series in the Bradford region. It lies immediately above the erosional unconformity at the top of the Knapp formation. The name Olean was applied to this member of the Pottsville by Ashburner[21] on account of the fine exposure of the conglomerate in the vicinity of Rock City, five miles south of Olean in Cattaraugus County, New York, and about 1½ miles northeast of the northeast corner of the Bradford quadrangle. This conglomerate, according to Butts,[22] can be traced southward along Allegheny River to a point two miles south of Tidioute, beyond which it apparently thins out and disappears.

At Rock City, locality 26, Plate C, the Olean conglomerate is 64 feet thick and predominatingly conglomeritic, only occasional layers of coarse quartz sandstone being present in it. Cross-bedding is a prominent feature. Most of the pebbles are vein quartz. The majority are milky but rose-colored ones also are present. Some of the quartz pebbles show a surface development of small crystal facets that give the pebbles an etched appearance. These have been formed by the deposition of secondary silica as a crystalline outgrowth upon individual crystalline quartz units of the original pebble. Glenn[23] mistakenly attributed this phenomenon to etching by waters containing humic acids. A few pebbles of white quartzite and dark gray slate also occur in the conglomerate. One rhyolite pebble was found. For the most part, the pebbles are well rounded, ovoid or ellipsoidal. Some of the larger ones measure 40x60x90 millimeters. Pebbles 30 millimeters long are fairly common and those 10 to 20 millimeters long are abundant. Subangular pebbles also occur particularly in the upper part of the member.

The conglomeritic phase of the Olean is also well displayed at Flatiron Rock, 1¾ miles northeast of Rock City, on Mount Raub and Hawkins Hill southeast of the city of Bradford, at the head of Niles Hollow, and at the head of West Branch. Plate 4B shows the conglomeritic and cross-bedded character of the Olean at Flatiron Rock and Plate 5A shows a typical outcrop west of Hazelton Mills near the head of West Branch.

The Olean loses its conglomeritic character in the southern part of the Bradford quadrangle. Over much of this area it consists of a medium to coarse-grained quartz sandstone very similar to the Connoquenessing. The following section was measured in the cut 1600 feet north of Bingham Station along the Buffalo, Rochester, and Pittsburgh Railroad:—

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[20] C. A. Ashburner, op. cit., pp. 192-193.

[21] C. A. Ashburner, op. cit., p. 56.

[22] Chas. Butts, Pre-Pennsylvania Stratigraphy. Report of Topographic and Geological Survey of Pennsylvania, 1906-1908, p. 193.

[23] L. C. Glenn, Devonic and Carbonic formations of southwestern New York: New York State Mus. Bull. 69, 1903, p. 983.

	Feet
Light gray coarse massive sandstone	4½
Coal (a local lens only)	1
Shale, black and carbonaceous at top	2
Gray medium-grained platy sandstone	3
Gray medium-grained massive cross-bedded sandstone	24
Gray clay containing abundant plant remains—a thin seam of coal occurs at the top and a thin lens of flat pebble quartz conglomerate near the base. Bottom of Olean	13
Light gray thin-bedded shale	6

The above section is shown graphically under locality 16 on Plate 3. The 13 feet of gray clay with a thin coal seam at the top represent the Lower Marshburg coal horizon of Ashburner.[24] He correlated this horizon with the Mauch Chunk formation, but the latter is now known to be absent in McKean County.[25] The coal and clay underlying the Olean at Bingham were apparently deposited in a depression on the pre-Pennsylvanian erosion surface shortly prior to the deposition of the sandstone and are, therefore, considered to be a part of the Olean.

At Taylor, 1½ miles northwest of Bingham, the Olean was quarried several years ago for the production of silica sand. It is 46 feet thick at this point. The upper portion consists of a coarse-grained buff quartz sandstone; the middle portion, of a coarse-grained light gray, almost white quartz sandstone with a conglomeritic layer at the base containing quartz pebbles, mostly angular, up to 5 millimeters in diameter; and the lower portion, a medium-grained light gray quartz sandstone. Occasional muscovite scales may be seen throughout the entire thickness.

Two screen analyses are given below, one of a sample of the sand as prepared by grinding and screening and the other of the sand that results after reducing this sample to individual grain size.

Table 2. Screen analyses of silica sand produced from Olean sandstone at Taylor, McKean County, Pa.

Size of opening in millimeters		1	2
Through	Caught on	Sand as produced, Percent by weight	Sand obtained by reducing to individual grain size. Percent by weight
4.699	3.327	5.9	1.8
3.327	1.651	23.0	11.9
1.651	.833	25.2	26.2
.833	.589	13.8	16.4
.589	.417	11.9	14.9
.417	.295	7.4	11.4
.295	.208	3.4	5.5
.208	.147	2.6	3.8
.147	.104	1.6	2.3
.104	.074	.1	1.7
.074	.053	1.7	1.0
.053		3.4	3.1

MISSISSIPPIAN SYSTEM

Whether Mississippian strata occur in the Bradford district has long been a mooted question. Between the base of the Olean and the top of the "Chemung" (dominantly marine Devonian) there are nearly 700 feet of strata, including, in descending order, the Knapp, Oswayo, and Cattaraugus formations whose age has been in dispute.

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[24] C. A. Ashburner, op. cit., p. 64.

[25] Chas. Butts, idem, p. 196.

Hicks[26] collected fossils from these rocks in McKean County, and he states:—

> "This list of species sufficiently exhibits the subcarboniferous [Mississippian] aspect of this fauna. It also shows an intermingling of Chemung and Waverly species which is a striking characteristic of this region of Pennsylvania as compared with the distinctness of Subcarboniferous and Devonian fossils in Central Ohio."

Ashburner[27], correlating on the assumption of the parallelism of formations, placed the Knapp and Oswayo in the Pocono group and the Cattaraugus in the Catskill. Later, Butts[28] suggested that strata included in the Pocono group in southwestern Pennsylvania, which are of Mississippian age, are absent in the Bradford district and that the Knapp and Oswayo formations lie below this group.

Glenn carried on detailed geological mapping during 1900 and 1901 in the Olean and Salamanca quadrangles in New York. This includes the northern portion of the Bradford district. He assigned the names Knapp, Oswayo, and Cattaraugus to the formations under discussion. On the basis of the field evidence and the paleontologic facts then available, he drew the Mississippian-Devonian boundary at the top of the Cattaraugus. In discussing the paleontological evidence, he makes the following statement[29]:—

> "The first Carbonic life forms appear with the incoming of the Wolf Creek conglomerate (basal member of Cattaraugus) and from this point up to practically the base of the Olean conglomerate at Olean rock city where the last Devonic forms disappear, there is a mingling of Devonic and Carbonic forms, the Devonic slowly decreasing, the Carbonic slowly increasing. The essential fact so far as the life of these Cattaraugus and Oswayo formations is concerned, is that there is an overlapping of Devonic and Carbonic faunas. Because of the thickness of these red beds (Cattaraugus) and their reasonably certain stratigraphic equivalence with the red beds of the Catskill to the east, and because of the unconformity believed to exist between the Cattaraugus and the Oswayo, the writer prefers to draw a provisional boundary between the Devonic and the Carbonic at this point."

Butts was associated with Glenn in the mapping of the Olean quadrangle and made extensive collections of fossils. He concluded that the boundary between the Mississippian and Devonian should be placed at the base of the Cattaraugus instead of at the top. In summarizing, he states[30]:—

> "This important faunal change with the incoming of the Wolf Creek conglomerate, taken in connection with the fact that on stratigraphic grounds, the equivalent of the Waverly of Ohio, of Sub-carbonic (Missis-

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[26] L. Hicks, Paleontology of McKean County: Pennsylvania Second Geol. Survey, Report R, 1880, p. 31.

[27] C. A. Ashburner, The Geology of McKean County: Pennsylvania Second Geol. Survey, Report R, 1880, pp. 64-72.

[28] Chas. Butts, Pre-Pennsylvanian stratigraphy: Report of the Pennsylvania Topo. and Geol. Survey, 1906-1908, p. 197.

[29] L. C. Glenn, Devonic and Carbonic formations of southwestern New York: New York State Mus. Bull. 69, 1903, pp. 985-986.

[30] Charles Butts, Fossil faunas of the Olean Quadrangle: New York State Mus. Bull. 69, 1903, p. 991.

> sippian) age, is pretty certainly present in the quadrangle, and in connection with the fact that the fauna of the conglomerate and higher beds contains a small Sub-carbonic element, would indicate that the bed might be provisionally adopted as the base of the Sub-carbonic in the quadrangle . . . . If this location is not accepted, there seems to be no paleontologic grounds for such a boundary line at all below the Olean conglomerate."

Clarke[31] concurred with Butts in placing the base of the Mississippian at the base of the Cattaraugus. The New York State Geological Survey[32] still draws the line between the Mississippian and Devonian systems at this horizon.

In 1904, Girty[33] proposed the term "Bradfordian series" for the strata comprising the Knapp, Oswayo, and Cattaraugus. Girty's reasons for introducing the term "Bradfordian" are stated as follows:[34]—

> "From Ohio, the Waverly group (Lower Mississippian) passes eastward into northwestern Pennsylvania. There, in his reports on Crawford and Erie Counties, I. C. White has called the several members by different names. The Black Hand conglomerate is his Shenango sandstone and apparently the Logan group is represented by his Shenango shale. His Meadville shale, Sharpsville sandstone, and Orangeville shale are, respectively, the upper, middle, and lower portions of the Cuyahoga shale. In this region, the Sunbury shale is either absent or merged with the lower Cuyahoga. The Berea grit of Ohio is White's Cussewago sandstone together with probably the Cussewago flags and Corry sandstone. From Crawford and Erie Counties, the Corry sandstone can be traced eastward to Warren, where it lies approximately 500 feet above the top of the true Chemung. The intervening beds seem, therefore, to represent a new time interval between the Devonian and the Carboniferous for which the name Bradfordian has been suggested . . . . Its age is a matter of some diversity of opinion but I believe that its true relations are with the Devonian."

In a later paper, Girty states definitely that he believes the Bradfordian series is of Devonian age. With reference to the fauna described by Butts from the Bradfordian series of the Olean region, he makes the following statement:[35]

> "The Carboniferous types cited by Mr. Butts make up a total of but seven out of a list of 59 species. All the rest are Devonian forms, most of which, and possibly all, have never been found in rock of Carboniferous age, so that were we to consider the question whether the faunas show a predominatingly Devonian or Carboniferous facies, there could be but one answer. It is only by adhering to the rule of 'first appearance' that these formations can with any justification be called Carboniferous."

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[31] John M. Clarke, Construction of the Olean rock section: New York State Mus. Bull. 69, 1903, p. 999.

[32] Winifred Goldring, Handbook of Paleontology, Part 2; The Formations: New York State Mus. Handbook 10, 1931, p. 424

[33] George H. Girty. Comparison of sections of Upper Paleozoic rocks in Ohio and northwestern Pennsylvania: Science, N.S. vol. XIX, 1904, pp. 24-25.

[34] George H. Girty, The relations of some Carboniferous faunas: Proc. Washington Acad. Sci., vol. VII, 1905, pp. 6-7.

[35] George H. Girty, Geologic age of the Bedford shale of Ohio: Annals New York Acad. Sci., vol. XXII, 1912, p. 307.

The Carboniferous forms listed by Butts[36] are *Ctenodus flabelliformis, Gyracanthus sherwoodi, Oehlertella pleurites, Orthothetes crenistria, Glossites (Sanguinolites) amygdalinus?, Sphenotus aeolus?, and Crenipecten winchelli.* Of two of the above, Butts himself questions the identification of the species. Girty questions the value of *Oehlertella pleurites, Orthothetes crenistria,* and *Crenipecten winchelli* for correlation purposes because specific identification of these forms is difficult.

In his report on the Warren quadrangle, Butts[37] treated the Oswayo and Cattaraugus formations as a unit under the name of Conewango formation. The red beds which serve to distinguish the Cattaraugus from the Oswayo in the Bradford region gradually disappear and the two formations become more and more alike westward so that it becomes impossible to distinguish them. The Conewango and the overlying Knapp are listed under Devono-Carboniferous rocks by Butts on the following grounds:

> "It is a mooted question whether the Conewango and Knapp formations, next to be described, should be included in the Devonian or in the Carboniferous system. They have generally been included in the Devonian and they certainly contain Devonian fossils . . . . However, a marked faunal change takes place at the base of these rocks. Most of the forms occurring so abundantly in the Chemung do not appear in the later beds but are succeeded by new forms, some of which have decided Carboniferous affinities. When this fauna was first studied at all carefully by Clarke and Butts, the opinion was expressed that these rocks might be regarded as Carboniferous, a view that has since been supported by more thorough study. It seems best to treat them, therefore, under the term Devono-Carboniferous rocks, by which their doubtful position is indicated."

Verwiebe,[38] after spending the 1916 and 1917 seasons in the field in northeastern Ohio and northwestern Pennsylvania, discussed the correlation of the Bradfordian. He places the Mississippian-Devonian boundary at the unconformity at the base of the Berea. This puts the Bradfordian series in the Devonian as, according to Girty's definition of this series, the Berea immediately overlies it.

White's correlation[39] of the Corry sandstone of northwestern Pennsylvania with the Berea of Ohio has never been seriously questioned. It is not clear, however, whether he also intended to include the underlying Cussewago shale and sandstone in this correlation. Prosser,[40] on the other hand, definitely correlated the Berea formation of Ohio with the Corry sandstone and the subjacent Cussewago shale and Cussewago sandstone. Chadwick[41] in review-ing the problem of the age of the Bradfordian, called attention to the lithological similarity between the Knapp conglomerate and the Cussewago sandstone. He concluded that the Cussewago shale, renamed Hayfield by him, and the Cussewago sandstone are the equivalent of the Knapp formation and are separated from the Berea-Corry by the Devono-Mississippian unconformity.

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[36] Charles Butts, Fossil faunas of the Olean Quadrangle: New York State Mus. Bull. 69, 1903, p. 991.

[37] Charles Butts, Description of the Warren Quadrangle: U. S. Geol. Survey Folio 172, 1910, pp. 4-5.

[38] Walter A. Verwiebe, The Berea formation of Ohio and Pennsylvania: Am. Jour. Sci., vol. XLII, July, 1916, pp. 43-58.
Correlation of the Mississippian of Ohio and Pennsylvania; Am. Jour. Sci., vol. XLIII, April 1917, pp. 301-318.
Correlation of the Devonian shales of Ohio and Pennsylvania: Am. Jour. Sci., vol. XLIV, 1917, pp. 33-47.

[39] I. C. White, The Geology of Erie and Crawford Counties: Pennsylvania Second Geol. Survey Report Q 4, 1881, p. 94.

[40] Charles S. Prosser, The Devonian and Mississippian formations of northeastern Ohio; Ohio Geol. Survey, 4th ser., Bull. 15, 1912, p. 396.

[41] George H. Chadwick, Chagrin formation of Ohio. Bull. Geol. Society of America, vol. 36, 1925, p. 463.

Caster[42] has re-examined essentially all the collections of fossils made in northwestern Pennsylvania and has spent three field seasons revising the stratigraphy. His recent monograph has gone far in clearing up many of the controversial points. He essentially substantiated Chadwick's correlation of the Knapp formation with the Hayfield shale and Cussewago sandstone but places the base of the Mississippian at the bottom instead of the top of the Knapp. In the Bradford district, Caster calls the Kushequa the basal member of the Knapp.[43] It contains the very characteristic Knapp fauna composed chiefly of *Syringothyris agulata, S. randalli,* and *Rhynchospirina (Eumetria) scansa,* common Mississippian types which are lacking in the underlying Oswayo shales. Besides carrying this high characteristic fauna, the shale in Warren County lies disconformably on the Oswayo shale.

In the present report the Knapp beds are tentatively listed under the Mississippian system.

KNAPP FORMATION

Glenn[44] applied the term Knapp to the formation immediately underlying the Olean at the village of Knapp Creek, which is half a mile north of the northeastern corner of the Bradford quadrangle. The outcrops which Glenn had an opportunity to examine are not well exposed at present although an excellent section of the underlying Oswayo can be seen along the road leading down to Fourmile Creek just north of the village. Glenn describes the outcrop at Knapp Creek as follows:

> "Here there are two coarse beds separated by a varying thickness of shale. In the gutter beside the road leading from Knapps Creek Station down into the head of Fourmile Creek, in the interval from 20 to 40 feet below the station level, is found a thin bedded gritty to pebbly sandstone heavily charged with iron and containing marine invertebrate fossils. The layers are separated by partings of blue clay shales. A few hundred yards west of the station along the electric road just before reaching the summit there is a second sandstone about 40 feet higher than the first one, the interval between being occupied by sandy ferruginous shales. It is bedded in layers a few inches thick, some of which contain a few pebbles. The layers are separated by ferruginous sandy shales. It is also fossiliferous, bearing among other forms *Syringothyris.* Above it are perhaps 20 feet of shale before the base of the Olean is reached."

The total thickness of the strata measured by Glenn at this locality is 65 feet. This horizon can be traced westward along the ridge nearly to Harrisburg.

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[42] Kenneth E. Caster, Stratigraphic relationships in northwestern Pennsylvania (abstract). Bull. Geol. Society America, vol. 44, 1933, pp. 202-203.

[43] Kenneth E. Caster, The stratigraphy and paleontology of northwestern Pennsylvania, Part 1, Stratigraphy: Bull. Am. Paleontology, vol. 21, No. 71, 1934, pp. 104-106.

[44] L. C. Glenn, Devonic and Carbonic formations of southwestern New York: New York State Mus. Bull. 69, 1903, pp. 980-981.

On June 5, 1926, Charles Butts and Paul D. Torrey collected the following fossils (list not published previously) from this horizon about half a mile southeast of Harrisburg, N. Y.:—

Orbiculoidea, Orthothetes, Productus sp., Spirifer disjunctus, Syringothyris, Camarotoechia (2 or 3 species probably undescribed), *Eumetria (Rhynchospira) scansa, Leptodesma orodes, Leptodesma curvatum, Allorisima?, Schizodus.*

According to Glenn,[44] the best development of the Knapp formation in the Salamanca quadrangle is on the ridge southwest of Limestone near the Pennsylvania line. The two thin conglomerates again occur just beneath the Olean. Each is more massive and more conglomeratic than in the Knapp Creek area. The upper one at least is fossiliferous. They are each 10 to 15 feet thick. The shale interval between varies from 30 to 40 feet in thickness and is fossiliferous, containing, among other forms, *Syringothyris*. There are about 20 or 30 feet of shale between the upper conglomerate and the base of the Olean. Farther south and west only one conglomerate, known as the Sub-Olean, was seen by Glenn beneath the Olean, and the shale interval is usually great enough to make it seem most probable that this one conglomerate is the lower of the two in the above mentioned localities, if both have not united westward.

Farther west along the above ridge, 1000 feet north of the Pennsylvania-New York line, along the Allegany State Park road at the head of Bennett Brook, Wallace E. Richmond and Paul D. Torrey made a collection of fossils in 1926 from the Knapp horizon. Charles Butts identified the lot and sent the following list to the writer:—

Eumetria (Rhynchospira) scansa, Leptodesma curvatum, L. orodes?, Paleoneilo? (Pelecypod having the contours of *Paleoneilo* but preserving no sign of hinge teeth), *Schizodus* sp.?, *Sphenotus? S. clavulus.*

Over that portion of the Bradford quadrangle west of the East Branch of Tunungwant Creek, the lower of the two conglomerates referred to by Glenn is usually present. Not more than one conglomerate was observed at any locality, the balance of the Knapp interval being occupied by sandstones and shales. The bottom of this conglomerate has been taken as the base of the Knapp formation over this part of the quadrangle. It is the conglomerate to which Ashburner[45] applied the term Sub-Olean. The actual base of the Knapp is perhaps somewhat lower in the section as some of the underlying unexposed shales may still be of Knapp age.

East of the East Branch of Tunungwant Creek, the conglomerate is rarely seen, its place being taken by sandstone. It is, therefore, difficult to draw the line between the Knapp and the Oswayo in this part of the quadrangle as the Knapp sandstones resemble some of the interbedded sandstones associated with the underlying Oswayo shales. As Caster has shown,[46] practically the only criterion for delimiting the Knapp and Oswayo in this area are the fossil faunas.

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[45] C. A. Ashburner, The Geology of McKean County: Pennsylvania Second Geol. Survey, Report R, 1880, p. 66.

[46] Kenneth E. Caster, The stratigraphy and paleontology of northwestern Pennsylvania, Part 1, Stratigraphy: Bull. American Paleontology, vol. 21, no. 71, 1934, pp. 103-104.

On the north side of Hedgehog Hollow in the northwestern part of the Bradford quadrangle, locality 1, Plate C, the interval between the base of the lower conglomerate of the Knapp and the base of the Olean is 66 feet. Nineteen feet of conglomerate are exposed at this locality, consisting of numerous thin milky quartz pebble layers interbedded with coarse light-gray sandstone. Pebbles up to 10 millimeters in diameter are present, many of which are discoidal. Occasional jasper pebbles also occur. The middle portion is markedly cross-bedded. At the head of Niles Hollow, 4¼ miles to the south, the erosional surface at the top of the Knapp cuts almost to the base of this conglomerate, leaving only 13 feet.

An unusually fine exposure of the lower Knapp conglomerate occurs just north of Tallyho on the east side of Wintergreen Run near its mouth above the new State highway. The photograph shown in Plate 5B was made at this locality. The 14-foot bed is conglomeratic throughout, shows pronounced cross-bedding, and contains marine fossils. It will be observed that the bed consists of several alternating horizontal and cross-bedded layers and that in the cross-bedded layers, not all the cross-laminations are inclined in the same direction. The interval between the base of the Olean, whose outcrop can be seen near the top of the cliff on the opposite side of the run, and the base of this conglomerate is 200 feet.

Most of the pebbles of the Knapp conglomerate are rounded. In contrast to the ovoid or ellipsoidal shape of the Olean conglomerate pebbles, however, they exhibit a pronounced tendency toward a flat or discoidal shape. Some of the largest in the Tallyho outcrop have lengths of 65 millimeters, widths of 45 to 50 millimeters, and thicknesses of 15 to 20 millimeters. As in the case of the Olean, they consist mostly of milky vein quartz. A few rose-colored ones were also observed. In marked contrast to the Olean, red jasper pebbles occur sparingly distributed throughout the Knapp conglomerate. This holds true not only for this particular outcrop but for every outcrop of the Knapp examined in detail in the Bradford district. Similar examinations of the Olean conglomerate, on the other hand, failed to reveal a single jasper pebble. Some of the pebbles of the Knapp also show secondary silica on individual quartz units of the aggregate comprising the pebble, deposited in such a manner as to develop crystal facets similar to those on some of the Olean pebbles.

Carll[47] was the first to notice the difference in shape of the pebbles in the conglomerates in the Bradford group and those of the Pottsville series. In commenting upon this feature, he called attention to the fact that the original structure of the quartz may have had something to do with the ultimate shape of the pebbles. Also that the shape of a pebble depends to a great degree upon the kind of attrition to which it has been subjected, and the length of time that it has been exposed to the action of abrading agencies. A fragment of rock propelled altogether by rolling acquires a rounded form, but if driven backward and forward, as by waves lashing upon the seashore, it eventually becomes flattened.

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[47] John F. Carll, The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties: Pennsylvania Second Geol. Survey, Report I 3, 1880, pp. 60-61.
Geological report on Warren County: Pennsylvania Second Geol. Survey, Report I 4, 1883, pp. 190-192.

The shape of the pebbles and the occurrence of occasional red jasper pebbles indicates an origin for the Knapp conglomerates similar to that of the Salamanca and other conglomerates of the Cattaraugus formation. It is practically impossible to distinguish the Knapp conglomerate in the western half of the Bradford quadrangle by its lithological characteristics from the Salamanca conglomerate as developed at its type locality at the Salamanca rock city.

The following fossils collected by the writer from the Tallyho outcrop were identified by Charles Butts: *Leptodesma orodes, Schizodus, Orthoceras, Spyroceras.*

The lower Knapp conglomerate is again exposed 1¼ miles southeast of the above locality on the southwest side of the new State highway about opposite Guffey. Here it is only 11 feet thick and consists largely of sandstone. The following section was compiled in this vicinity, locality 20, Plate C:

Section including lower Knapp conglomerate near Guffey

	Feet
Black carbonaceous shale	2.0
Coal—Middle Alton	1.5
Covered	16.0
Bony coal—Lower Alton	.5
Covered	78.0
Buff-colored, massive, coarse-grained sandstone with occasional quartz pebble layers and lenses—the pebbles are small, both rounded and subangular ones being present—Olean	27.0
Base of Pottsville series	
Greenish-gray sandy shale	30.0
Light greenish-gray fine-grained sandstone, somewhat shaly	10.0
Greenish-gray sandy shale with thin layers and lenses of fine-grained greenish-gray shaly sandstone	50.0
Light greenish-gray fine-grained sandstone, somewhat shaly	5.0
Covered	81.0
Light-gray, massive sandstone with some thin quartz pebble layers and lenses—many of the pebbles are discoidal—lower Knapp conglomerate	11.0
Base of Knapp formation	
Covered	213.0
Base of Oswayo formation	
Red shale—Cattaraugus formation	

It will be observed that the interval between the base of the Olean and the base of the lower Knapp conglomerate has increased from 70 feet at the Hedgehog Hollow section to 187 feet in the Guffey section, the thickness of the underlying Oswayo having remained essentially the same, being 197 feet at Hedgehog Hollow and 213 at Guffey. The 95 feet of sandy shales and associated shaly sandstones immediately underlying the Olean at Guffey occupy the stratigraphic position of the Hayfield shale of Erie and Crawford Counties and have been included with the Knapp on the areal geologic map, Plate B. No fossils were collected from these beds at the Guffey locality. If any are present, they are not conspicuous. Five miles east of the Guffey section, at Gaffney, locality 19, Plate C, the lower portion of the Knapp formation is well exposed in the quarry of the Kushequa Brick Company on the northwest side of the valley. Here the following section was measured:

Section of lower Knapp formation at Gaffney

	Feet
Massive coarse sandstone, markedly cross-bedded (Olean)	24.0
Covered	92.0
Medium to coarse quartz sandstone, upper 6 inches conglomeritic	4.0
More massive fine- to medium-grained light-gray sandstone	7.0
Dark-gray fissile shale	1.1
Conglomeratic sandstone, quartz pebbles in part discoidal, markedly calcareous where it has not been leached by weathering. Contains fish remains	1.1
Light-gray fissile shale	2.5
Olive-gray thin-bedded, in part fissile shale with numerous thin fine-grained argillaceous sandstone seams toward top (material quarried)	45.0
Platy fine-grained light greenish-gray sandstone	4.6
Massive light greenish-gray sandstone	4.6
Thin-bedded olive-gray shale and sandy shale with numerous thin seams of fine-grained greenish-gray argillaceous sandstone	16.0
Fissile dove-gray shale	22.0
Bluish-gray very calcareous conglomerate of quartz pebbles up to 10 mm. in diameter, many discoidal	1.5
Fine-grained greenish-gray sandstone	1.0
Olive-gray shale	2.5
Bluish-gray calcareous sandstone	1.5
Olive-gray shale, in part sandy	11.5
Covered to bed of creek at west end of brick plant	21.5

Caster[48] considers the entire section exposed at Gaffney as Knapp. Near the bottom of the section, 200 feet below the base of the Olean, a thin bed of conglomerate occurs which corresponds very closely in stratigraphic position to the conglomerate identified as the lower of the Knapp conglomerates in the Tallyho and Guffey sections. Between Tallyho and Guffey, a distance of 1¼ miles in a southeasterly direction, this bed changes from 14 feet of coarse conglomerate to 11 feet of sandstone with only occasional pebble layers and lenses. It is not unreasonable to assume, therefore, that in another five miles eastward it should thin to only 2½ feet of conglomerate and sandstone. The writer's interpretation of the Gaffney section, therefore, is that the lower part is the equivalent of the interval occupied by the Knapp conglomerates in the western and northwestern portions of the Bradford quadrangle and that the upper part, mostly concealed, represents the Hayfield member of the Knapp. This is not in agreement with Caster's interpretation, which is that the sandstone at the top of the exposed part of the section, 92 feet below the base of the Olean, represents the lower Knapp conglomerate and that the underlying shales and associated sandstones, which he calls the Kushequa shale member of the Knapp, are older than the conglomerates.

The upper 45 feet of shale exposed at this locality, shown in Plate 5C, have been used in the manufacture of brick, tile and chemical stoneware.

The Knapp formation is exposed in several cuts along the Buffalo, Rochester and Pittsburgh Railroad, between the base of the Olean, 1,600 feet north of Bingham station and a point 3,100 feet northwest of Taylor. Nearly 160 feet is exposed in this interval. It was impossible to determine exactly the contact between the Knapp and the underlying Oswayo as the lower Knapp conglomerate was not recognized. Here again the upper part, which has been included in the Knapp on the areal geologic map, very likely is the equivalent of the Hayfield member of this formation.

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[48] Kenneth E. Caster, Op. cit., Stratigraphy and Paleontology, pp. 107-109.

The following section was measured 3,200 feet north of Bingham station along the Buffalo, Rochester and Pittsburgh Railroad, locality 15, Plate C:

	Feet
Light-gray coarse sandstone with subangular quartz pebbles, Olean	20.0
Light-gray shale with interbedded thin sandstone layers; toward base some of these contain marine fossils	15.0
Almost white, coarse-grained massive sandstone	8.0
Light-gray, finely laminated shale	5.4

A view of this cut is shown in Plate 2C. From the shale immediately above the lower sandstone in the above section, Charles Butts, in 1926, collected *Chonetes*, cf. *C. burlingtonensis* and *Rhipidomella*, cf. *R. oweni* and from the sandstone, *Schizodus* sp?. From the shales immediately below the sandstone, he obtained plant remains which were identified by David White as follows: *Archeopteris obtusa*, Fern ? Genus and species ? *Lepidodendron* ? Decorticated stem with *Cyclostigma* features, cf. *L. gaspianum*.

The occurrence of forms of *Chonetes* and *Rhipidomella* closely resembling species of these genera that are characteristic of rocks of Kindernook (early Mississippian) age would seem to indicate that these strata should be placed in the Mississippian system. The collection of plant remains, however, as far as it goes, according to David White, indicates a Devonian age. The plants characteristic of the Pocono (early Mississippian) are not represented. The beds are considered equivalent to the Hayfield and have been included with the Knapp on the geologic map.

Continuing northwestward, the following section is exposed 3,200 feet southeast of Taylor at locality 14, Plate C:

	Feet
Greenish-gray sandy shale	3.0
Gray, very coarse-grained massive sandstone	6.5
Gray fissile sandy shale	15.0
Interbedded gray sandy shale and sandstone; some of the sandstone layers are very coarse and contain small discoidal quartz pebbles	9.0
Light-gray, almost white, medium-grained thick-bedded sandstone	8.0

The top of this section corresponds approximately to the base of the section measured at locality 15.

At Taylor, locality 13, Plate C, the following section was compiled:

	Feet
Gray, coarse quartz sandstone, Olean	46.2
Covered	109.0
Light-gray platy fossiliferous sandstone, somewhat shaly, shows ripple marks on bedding planes and contains clay galls	3.0
Olive-green shale	2.0

From the fossiliferous sandstone Charles Butts, in 1926, collected *Spirifer disjunctus*, *Orthothetes*, *Camarotoechia*, cf. *C. contracta*, and *Leptodesma*, cf. *L. maclurii*. Ten to 20 feet above this horizon a specimen of *Spyroceras* was found in the cut southeast of Taylor.

The following section occurs in the cut 1,800 feet northwest of Taylor at locality 12, Plate C. This section overlaps the fossiliferous horizon at Taylor, as is shown on Plate 3, where the sections have been lined up according to their positions with respect to sea-level. Its top, stratigraphically, is about 25 feet below the base of the section measured at locality 14.

	Feet
Olive-green shale	10.8
Greenish-gray sandy shale with interbedded thin sandstone layers	6.8
Light-gray fine-grained sandstone, somewhat shaly	3.0
Bluish-gray shale	17.1
Olive-green sandy shale	4.2
Greenish-gray platy, shaly sandstone	5.0
Gray, fine-grained, very fossiliferous sandstone	.8
Olive green sandy shale	2.1

Continuing northwestward 1,300 feet at locality 11, Plate C, another cut exposes the following section, the upper half of which overlaps stratigraphically the lower part of the section given above.

	Feet
Olive-green shale	10.8
Olive-green sandy shale	17.3
Light greenish-gray fine-grained fossiliferous sandstone, somewhat shaly	3.0

Paul D. Torrey, in 1926, made collections from the fossiliferous horizons at localities 11 and 12 in which Charles Butts identified the following forms:

Oehlertella pleurites
Orthothetes sp ?
Productus sp ?
Shumardella, cf. *S. missouriensis*
Camarotoechia, one or two species
Spirifer disjunctus
Athyris polita
Eumetria (*Rhynchospira*) *scansa*
Leptodesma curvatum
L. orodes
L. maclurii
L., undescribed species
Dipterus minutus

In commenting upon this collection, Charles Butts makes the following statement[49]:

> The important members of this faunule are **Eumetria (Rhynchospira) scansa**, the **Productus**, and the **Shumardella**. The first, in connection with the abundant Camarotoechias and the Leptodesmas, tie this horizon in with the Knapp sandstone in which occur the fossils of the next preceding list. (Refers to collection obtained one-half mile southeast of Harrisburg, N. Y., already described.) The absence of **Syringothyris** is, however, notable as is also the presence of **Productus** and **Shumardella.** All three genera are rated as Mississippian fossils and appear in the Kinderhook beds, the basal Mississippian of the Mississippi Valley. They point to the early Mississippian age of the "Catskill" (Conewango) of this region. **Rhynchospira scansa** belongs to the genus **Eumetria,** a Mississippian genus. The occurrence of **Archeopteris** 100 feet above this faunule is also notable as that genus is regarded as Devonian. These are contradictory facts which will necessitate a revision of our ideas as to the time value of the fossils concerned.

On the evidence of fossils, the base of the section at locality 11 has been taken as the approximate base of the Knapp formation. Between this base and that of the Olean are about 160 feet of strata.

DEVONIAN SYSTEM

OSWAYO FORMATION

The greenish-gray sandy shales with interbedded shaly and frequently fossiliferous sandstone layers, which lie beneath the Knapp and above the Cattaraugus red beds in the Bradford region, comprise the Oswayo formation. The type locality for this formation is Oswayo Creek which empties into Allegheny River one mile above Portville, southeast of Olean, New York.

This formation varies little in thickness in the Bradford quadrangle. At the head of Fourmile Creek, 9 miles northeast of Bradford, the thickness is 209 feet; at the head of Hedgehog Hollow, 3 miles northwest of Bradford, 198 feet; and at Guffey, 14 miles south, 213 feet.

Practically the entire thickness of the formation is exposed along the road leading down to Fourmile Creek, north of Knapp Creek village, locality 27, Plate C, where the following section was measured:

Section of Oswayo formation near Knapp Creek, N. Y.

	Feet
Interbedded layers of greenish-gray platy shaly sandstone and shale	53.3
Greenish-gray fissile shale with occasional thin layers of shaly sandstone	7.5
Greenish-gray, fine-grained shaly sandstone	13.5

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[49] Charles Butts, written communication, June 29, 1926.

Greenish-gray shale	19.1
Greenish-gray fine-grained fossiliferous sandstone	11.5
Greenish-gray sandy shale	26.1
Greenish-gray fine-grained fossiliferous sandstone	1.0
Greenish-gray sandy shale with occasional thin layers of fine-grained sandstone	21.1
Greenish-gray shale	13.1
Interbedded greenish-gray sandy shale and thin layers of shaly sandstone	17.4
Very fossiliferous limestone—Marvin Creek coquinite	.75
Greenish-gray shale	12.85
Greenish-gray fine-grained shaly sandstone with some interbedded sandy shale	9.9
Cattaraugus red shale	

The bed of limestone 23 feet above the base of the section probably is the limestone which Ashburner[50] called the Marvin Creek.

Caster[51] has renamed this limestone the Roystone, stating that Ashburner was not sufficiently exact in his definition of the type locality and that the limestone which Ashburner saw along Marvin Creek is one of the calcareous horizons in the lower part of the Knapp formation. The writer cannot subscribe to this interpretation of Ashburner's use of the term. Ashburner made the Oswayo the lower member of his Pocono formation. He definitely states that the Marvin Creek limestone occurs near the bottom of this Pocono and mentions two localities where its outcrop can be seen, one along Sheppard Run in southern Bradford Township and the other on the western slope of Chapel Hill in the northern part of Sergeant Township. In each case, the position of the limestone in the section is given. The writer has visited both localities. Along Sheppard Run the limestone crops out in a cut on the southeast side of the new State highway about 1½ miles above Custer City. It is 2½ feet thick and lies about 60 feet above the highest exposed red shales of the Cattaraugus formation. East of Marvin Creek valley on the west slope of Chapel Hill along Irons Hollow road, about 1½ feet of the five feet of limestone, which Ashburner designated as the Marvin Creek, are exposed. The horizon is between 60 and 70 feet above the highest exposed red beds of the Cattaraugus formation.

The Marvin Creek limestone in the Bradford quadrangle is composed largely of more or less broken brachiopod and other marine shells imbedded in a sandy matrix. It is essentially a consolidated coquina or coquinite. At the head of Indian Creek, 2½ miles east of Knapp Creek, two limestone beds occur 20 feet apart. The upper bed is 14 inches thick and the lower 13 inches. The lower bed lies 47 feet above the top of the Cattaraugus red shales. West of Knapp Creek, 1½ miles, the limestone is 3½ feet thick and 28 feet above the top of the Cattaraugus. East of Dallas City it is one foot thick and 66 feet above the red beds. On the north side of Columbia Hill, southeast of Rixford, the limestone has a thickness of 2 feet and the interval is 72 feet. Half a mile east of Tallyho on the north side of Kinzua Creek in the southwestern part of the quadrangle, the interval is 68 feet.

South and west of Droney station along the Buffalo, Rochester and Pittsburgh Railroad, the middle part of the Oswayo is exposed in several cuts along the south side of Railroad and Droney runs. The following section was measured 3,200 feet west of Droney station on the south side of Railroad Run, where the railroad makes a sharp turn (locality 10, Plate C):

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[50] C. A. Ashburner, The geology of McKean County; Pennsylvania Second Geol. Survey Report R, 1880, pp. 68-69 and 167.
[51] Kenneth E. Caster, Op. cit, pp. 97 and 105-111.

	Feet
Olive-green sandy shale	6.0
Light greenish-gray fine-grained sandstone, somewhat shaly	2.0
Olive-green fissile shale with a few thin sandstone layers near top	19.8
Greenish-gray fine-grained sandstone, somewhat shaly	1.5
Olive-green fissile shale	10.3
Greenish-gray sandy shale with thin fossiliferous sandstone layers	2.5
Olive-green fissile shale	1.5

In a collection of fossils made by Paul D. Torrey, in 1926, at this locality, Charles Butts identified *Spirifer disjunctus* and *Camarotoechia allegania.*

About 600 feet south of Droney station (locality 9, Plate C) and approximately 10 feet stratigraphically below the previous section, the following section is exposed:

	Feet
Light greenish-gray fissile shale, somewhat sandy	5.4
Light greenish-gray sandy shale	5.4
Light greenish-gray fine-grained platy sandstone, somewhat shaly	2.5
Light greenish-gray sandy shale, very fossiliferous	12.9
Greenish-gray fine-grained shaly sandstone, fossiliferous	2.0
Olive-green fissile shale	5.8
Limestone, very fossiliferous, Marvin Creek coquinite	2.0

The base of the above limestone lies approximately 60 feet above the base of the Oswayo at this point. The Oswayo in the vicinity of Droney is estimated to be 210 feet thick. In collections of fossils made by Paul D. Torrey at this locality, in 1926, Charles Butts identified the following:

Spirifer disjunctus
Camarotoechia, cf. *sappho*
Orthothetes
Ptychopteria, two or more species
Aviculopecten, cf. *A. duplicatus*

In limestone
Spirifer disjunctus
Camaretoechia, large, probably undescribed species
Pararca venusta
Leptodesma, one or more species
Ptychopteria, one or more species

CATTARAUGUS FORMATION

The name Cattaraugus was given by Glenn[52] to the succession of red shales interbedded with greenish-gray shales and fine-grained, greenish-gray, thin-bedded, micaceous sandstones which occur between the Oswayo and the "Chemung" shales in Cattaraugus County, New York, and extend southward into Pennsylvania. Glenn recognized three rather well-defined conglomerate horizons in the Cattaraugus formation in the Olean and Salamanca quadrangles, namely, in descending order, the Killbuck (Tuna), Salamanca, and Wolf Creek. All three of these conglomerates are characterized by flat or discoidal quartz pebbles accompanied by occasional red jasper pebbles.

The Tuna conglomerate,[53] later renamed Killbuck by M. L. Fuller,[54] occurs in the upper part of the Cattaraugus and is of local importance only, being confined largely to an area centering about Killbuck in the west-central part of the Salamanca quadrangle. The Venango First oil sand occupies approximately the same stratigraphic horizon as the Tuna conglomerate[55].

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[52] L. C. Glenn, Devonic and Carbonic formations of southwestern New York: New York State Mus. Bull. 69, 1903, p. 973.

[53] John F. Carll, Geological report on Warren County: Pennsylvania, Second Geol. Survey Report I 4, 1883, p. 204.

[54] L. C. Glenn: Op. cit., p. 977.

[55] Kenneth E. Caster, Stratigraphic relationships in northwestern Pennsylvania (abstract): Bull. Geol. Soc. America, vol. 44, 1933, p. 203.

The Salamanca conglomerate, the most widespread of the three, occurs near the middle of the formation. The Venango Second oil sand corresponds closely in stratigraphic position to the Salamanca conglomerate. The Wolf Creek (Panama) conglomerate, like the Tuna, is also of more or less local occurrence. The Venango Third oil sand occupies approximately the stratigraphic horizon of this conglomerate. At its type locality on Wolf Creek, seven miles east of Olean, the Wolf Creek conglomerate forms the basal member of the Cattaraugus formation.

In the Bradford quadrangle, the dividing line between the Oswayo and Cattaraugus has been drawn at the top of the highest red shale found in the section. A fine-grained, greenish-gray, micaceous and argillaceous sandstone frequently occurs immediately above this shale, but the Tuna conglomerate itself was nowhere observed. The nearest outcrop of typical Wolf Creek conglomerate observed occurs east of the Bradford quadrangle along the State highway, half a mile north of Coryville, in Eldred Township. At this locality, the conglomerate has a maximum thickness of four feet and contains marine fossils. Red shale occurs a short distance above it, but none was observed below it. Inasmuch as the typical Wolf Creek conglomerate does not occur in the Bradford quadrangle, the lowermost red shale has been taken as the base of the formation. Only a short distance below this horizon marine fossils are usually found in considerable abundance in the bluish- and greenish-gray sandy shales comprising the "upper Chemung."

Since the strata above and below both contacts consist of shales and shaly sandstones that weather readily, good exposures of the actual contacts are of comparatively rare occurrences. Much care has to be exercised in the case of any particular exposure in order to determine with any certainty that the uppermost or lowermost red layer, whichever the case may be, is the one represented.

In Hedgehog Hollow (locality 1, Plate C) in the northwestern part of the quadrangle, the Cattaraugus has a total thickness of 345 feet; at Hawkins Hill, 1½ miles southeast of Bradford (locality 4, Plate C), 294 feet; at the abandoned shale quarry on the west side of East Branch valley just north of Lewis Run (locality 5, Plate C), 300 feet; at the shale quarry in Lewis Run on the opposite side of the valley (locality 6, Plate C), 295 feet; at the head of Harrisburg Run in the northeastern part of the quadrangle, 345 feet; and on the north side of Columbia Hill, southeast of Rixford, 311 feet. An examination of a complete set of samples of the drill cuttings from the Petroleum Reclamation Company's West Looker No. 254 well at the head of Garlock Hollow (Well 1, Plate C) showed an interval of 335 feet between the top of the highest and the bottom of the lowest red shale beds of the Cattaraugus; the same company's North Looker No. K-17 well near the head of Baker Run (Well 2, Plate C), an interval of 294 feet;[56] and the C. W. Dennis and Company's No. 1 well, ¾-mile southwest of Bradford (Well 3, Plate C), 250 feet.[57]

With the exception of the Dennis well record given by Ashburner, the thickness of the Cattaraugus at the other eight localities, widely distributed over the northern half of the Bradford quadrangle, ranges from 294 to 345 feet. Taking into consideration the difficulty of obtaining accurate measurements on the top and bottom of the formation and the fact that the individual beds of red shale are not continuous, but interfinger with gray shales, as can be clearly seen where sections covering the same interval are measured at points even less than half a mile apart, the above variation is comparatively small and does not indicate an erosional unconformity at the top of the Cattaraugus of the magnitude suggested by Glenn.[58]

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[56] J. B. Newby, P. D. Torrey, C. R. Fettke, and L. S. Panyity, Bradford Oil Field, McKean County, Pennsylvania and Cattaraugus County, New York: Structure of Typical American Oil Fields, vol. II, 1929, p. 423.

[57] C. A. Ashburner, The geology of McKean County; Pennsylvania Second Geol. Survey Report R, 1880, p. 288.

Glenn apparently assumed that the Salamanca conglomerate, as developed in the Salamanca quadrangle, represents a practically continuous horizon and that because the distance from the top of this conglomerate to the top of the Cattaraugus varies all the way from 65 to 240 feet, the upper surface of the Cattaraugus is irregular because of erosion. There is, consequently, an unconformity of such magnitude at this point representing an erosion interval between the Cattaraugus and the succeeding Oswayo. The writer found no evidence of an unconformity of such magnitude at this horizon in the Bradford quadrangle. Observations made in this area seem to indicate that the conglomerates and sandstones seen at various points at approximately the Salamanca horizon do not represent one continuous bed but comprise several disconnected and discontinuous lentils, in part perhaps overlapping, which, instead of occupying one definite horizon in the Cattaraugus, occur over a considerable interval near the middle of the formation. It does not necessarily follow from this that the use of the term Salamanca should be discontinued, provided one keeps in mind that the horizon of this member of the Cattaraugus is not a continuous stratum, but represents an interval near the middle of the formation which is usually characterized by the presence of a prominent lentil of sandstone or conglomerate.

The lower portion of the Cattaraugus is well exposed in several shale quarries in the vicinity of Lewis Run. The following section was compiled at the one operated by the Hanley Company (locality 6, Plate C).

	Feet
Top of Cattaraugus red shale	
Covered	45.0
Greenish-gray medium-grained platy sandstone	5.0
Covered	113.5
Greenish-gray and reddish-gray fine-grained platy micaceous and argillaceous sandstone	6.0
Greenish-gray medium-grained massive sandstone; contains numerous plant fragments, some fish remains, and fragments of small shells in certain layers—rill marks on bedding planes—Salamanca	11.6
Greenish-gray shale with occasional thin sandstone lentils with a few small discoidal quartz pebbles	45.3
Variegated red and yellowish-green shale	15.3
Dark reddish to purplish-gray fine-grained sandstone, very fossiliferous; contains a few quartz pebbles in upper part; up to 3 x 8 x 10 mm.—Hanley	14.0
Greenish-gray shale, in part sandy	5.5
Brick-red shale containing several lenticular beds of greenish-gray fine-grained sandstone up to 10 inches thick	21.5
Covered to base of Cattaraugus, estimated	13.0

The 11.6 feet of sandstone occurring 169.5 feet below the top of the Cattaraugus is thought to represent the Salamanca horizon in this section. It can be seen near the top of the cliff in Plate 6A. In 1926, Paul D. Torrey

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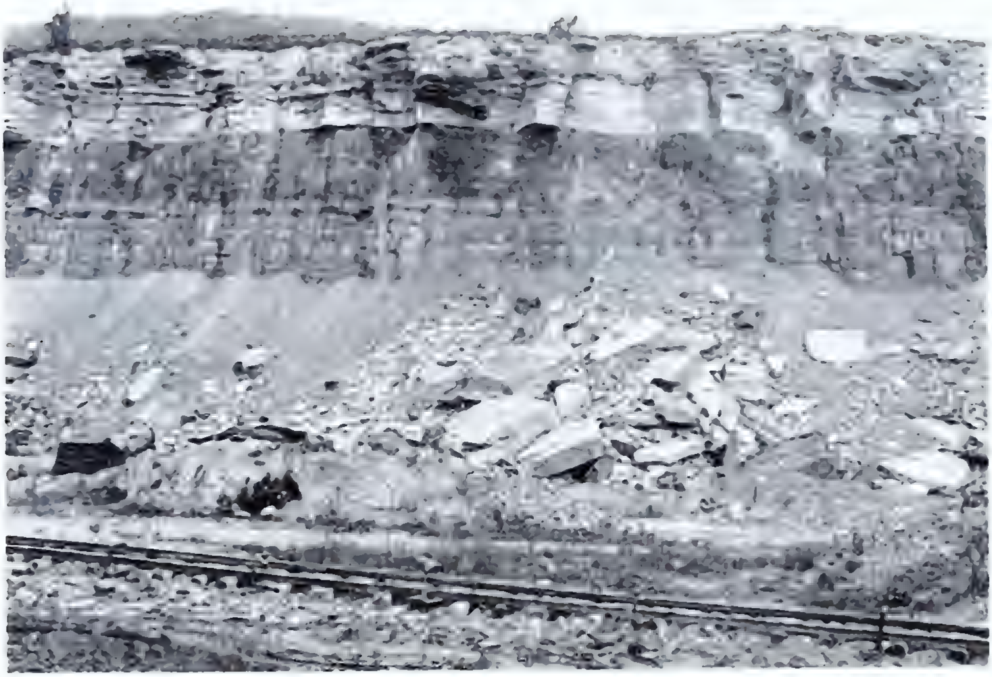
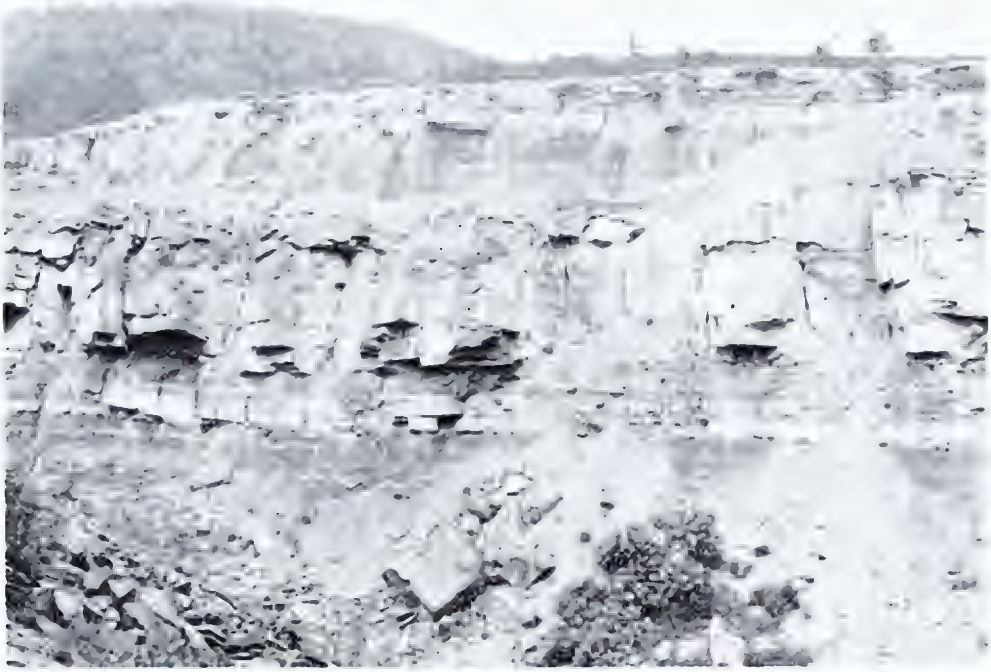
[58] L. C. Glenn, Devonic and Carbonic formations of southwestern New York: New York State Mus. Bull. 69, 1903, pp. 977-978.



A. Upper bench of shale quarry at Hanley Company's plant, Lewis Run, showing Salamanca sandstone near top of cliff.



B. Hanley sandstone in foreground, Salamanca sandstone near top of cliff in distance. Same quarry as above.

made a collection of fish remains from this horizon in which Dr. J. W. Gidley recognized the following forms, characteristic of the late Devonian—*Dipterus* sp. ?, *Cladodus* cf. *C. springeri*, *Dinichthys pustulosus*, *Asterolepsis* species.

Sixty feet below this sandstone, there occurs another more prominent sandstone (Plate 6B), 14 feet thick, of fine- to medium-grained texture and dark reddish- to purplish-gray, which will be referred to hereafter as the Hanley. Discoidal quartz pebbles up to 3 x 8 x 10 mm. occur sparingly distributed through the upper part. This sandstone contains an abundance of marine fossils. Charles Butts comments as follows on the forms identified.[59]

Spirifer disjunctus. Common throughout the Catskill equivalent in this region.

Modiola praecedens. Common in the lower part of "Catskill" (Cattaraugus) of region. It begins in the Wolf Creek conglomerate of Allegany and Cattaraugus Counties, New York, but has not been recognized at a lower horizon..

Oehlertella pleurites. Common in the Wolf Creek conglomerate and "Catskill" (Cattaraugus) of region but not found at a lower horizon. Has been found in base of "Catskill" on Allegheny Front near Altoona.

Sphenotus contractus. Common in "Catskill" (Cattaraugus) and "Chemung" of region.

Schizodus cf. *chemungensis.* Common in "Chemung" and "Catskill" of region.

Grammysia cf. *communis.*

Leptodesma orodes or *mytiliforme.* Common "Catskill" (Cattaraugus) forms.

Pararca venusta. This and one or two other species of *Pararca* confined to the "Catskill" of this region. Not hitherto known below the Salamanca conglomerate, which lies about the middle of the "Catskill" (Cattaraugus).

Nuculites? New forms for region showing general outlines of *Nuculites* and with a clavicular furrow on the mold as in that genus.

Large pelecypods. Two or three species of what appear to be an undescribed genus of Grammysiidae.

Orthoceras?

Spyroceras? An annulated orthoceroid agreeing with *Spyroceras* but having no longitudinal striae or at least having none preserved.

Dipterus minutus

The Hanley sandstone occurs approximately half way between the Salamanca and Wolf Creek horizons. It apparently is a local development. On the west side of the valley and only half a mile distant (loc. 5, pl. C), it should appear in the old Foster quarry at or near the top of the exposed face, but no sandstone resembling it lithologically occurs at this locality where the following section was measured:—

Section in Foster quarry at Lewis Run

	Feet
Interbedded greenish-gray shale and shaly sandstone	14.8
Greenish-gray fine-grained micaceous sandstone with abundant carbonized plant remains	8.0
Greenish-gray shale	1.5
Brick-red shale	19.8

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[59] Charles Butts, Written communication, May 1, 1926.

Greenish-gray sandy shale	1.1
Brick-red shale	5.9
Brick-red micaceous and shaly sandstone with abundant shell fragments	2.0
Brick red shale	.7
Base of Cattaraugus	
Greenish-gray shale	.3
Greenish-gray cross-bedded fine-grained micaceous sandstone	1.0
Interbedded bluish-gray shale and fine-grained sandstone	18.2
Greenish-gray sandy shale with interbedded thin shaly sandstone layers containing marine fossils	8.4
Greenish-gray shale	5.0
Greenish-gray sandy shale	1.1
Greenish-gray fissile shale	3.3
Greenish-gray shaly sandstone with an occasional marine fossil	1.1
Greenish-gray fissile shale	6.0
Greenish-gray shaly sandstone	2.2
Covered	10.8
Brown fine-grained sandstone	5.5

The two quarries at localities 7 and 8, Plate C, one-third mile south of the Hanley quarry, on account of the southeasterly dip of the beds in this vicinity, are too high stratigraphically to expose the horizon of the Hanley sandstone. The Salamanca sandstone appears near the top of the sections exposed. In the south quarry, the upper three feet of the sandstone are conglomeratic, containing quartz pebbles up to 20 millimeters in diameter many of which are discoidal. This part contains marine fossils, including brachiopods. Plant remains occur in the basal part.

The shales between the Salamanca and Hanley sandstones and those immediately below the Hanley and, at the old Foster quarry including a portion of the upper Chemung (Chautauquan), have been extensively utilized near Lewis Run for the manufacture of common red building brick, face brick, and floor tile. Plants and quarries have been operated at four localities, but in recent years only the Hanley Company plant has been active.

Lithologically, the Cattaraugus formation, in many respects, resembles the Catskill of southeastern New York and eastern and central Pennsylvania. Traced eastward by outcrops and well records, the two are found to merge into one another. This does not necessarily imply contemporaneity in age, however. The Catskill type of sedimentation started much earlier in southeastern New York and eastern Pennsylvania than in the western parts of these States and it is now known that even the uppermost of the Catskill strata in the Catskill region are considerably older than the Cattaraugus beds of western New York and adjacent portions of Pennsylvania. This was pointed out as early as 1887 by Williams,[60] when he stated that there is reason to believe that in Sullivan County, New York, the deposition of red beds started as early as Hamilton time, an observation which has recently been verified by Chadwick and Cooper in the Catskill area of New York and by Willard in northern New Jersey.[61]

As pointed out under the description of the fauna of the Hanley sandstone, Butts notices a resemblance between some of the forms in that sandstone and those which he has collected from the basal Catskill along the

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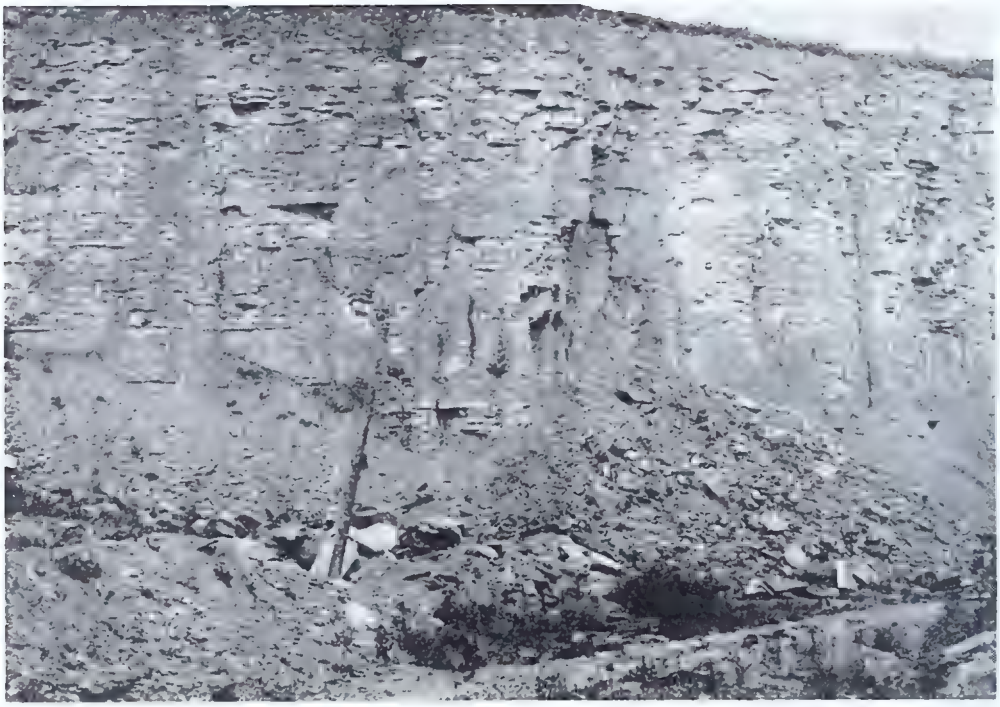
[60] Henry S. Williams, On the fossil faunas of the Upper Devonian: the Genesee section, New York: U. S. Geol. Survey Bull. 41, 1887, p. 27.

[61] George H. Chadwick, Catskill formation (abstract): Bull. Geol. Soc. America, vol. 42, 1931, pp. 242-243.

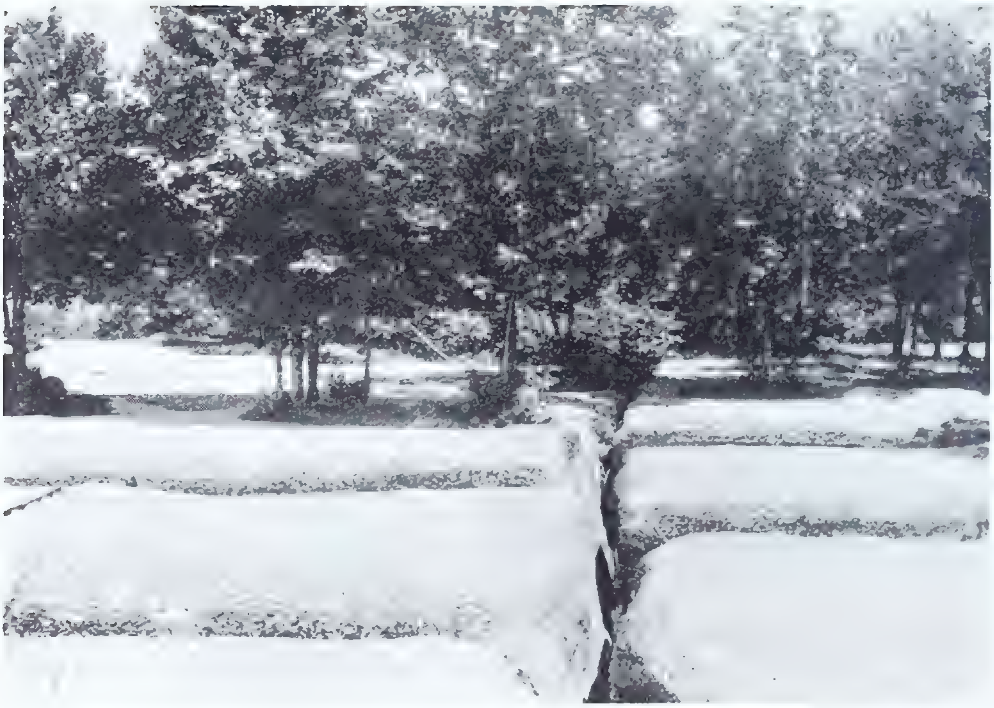
Hamilton red beds in eastern New York; Science, n. s., vol. 77, 1933, pp. 86-87.

G. Arthur Cooper, Stratigraphy of the Hamilton group of eastern New York (abstract): Bull. Geol. Soc. America, vol. 44, 1933, p. 200-201.

Bradford Willard, "Catskill" sedimentation in Pennsylvania: Bull. Geol. Soc. America, vol. 44, 1933, pp. 495-516.



A. Upper Chemung, abandoned quarry of Hanley Company near southern limits of City of Bradford.



B. Joints enlarged by weathering, surface of Olean conglomerate at Rock City, south of Olean, N. Y.

Allegheny Front west of Altoona. In the Altoona region, the Catskill formation has a thickness of from 2000 to 2500 feet.[62] It seems reasonable to assume that at least part of the Cattaraugus is represented in the Catskill section at Altoona. Whether the Oswayo is also the equivalent in age of part of the Catskill as represented in the latter section or whether this formation, if its equivalent is present at all, is represented by strata which have been included in the Pocono in that section, is not as yet definitely known.

In tracing the Cattaraugus westward into the Warren quadrangle, the red beds gradually disappear and it becomes impossible to distinguish the Cattaraugus from the Oswayo. Butts has, therefore, grouped them together under the Conewango formation. In discussing the correlation of the Conewango, he states:[63]

> It appears that the Conewango is the equivalent of some part of the Catskill formation, as it comes upon the Allegheny Front near Altoona, Pennsylvania from beneath the trough occupied by the bituminous coal fields of Pennsylvania. The actual transition horizontally appears to be in the nature of an interfingering of red and green beds, the green beds with a marine fauna thinning out southeastwardly and the red beds with fish remains thinning out northwestward.

The Cattaraugus formation of the Bradford district represents approximately the same stratigraphic interval as that occupied by the Venango oil sand group of the Venango district as originally defined by Carll.[64]

CHEMUNG GROUP (CHAUTAUQUAN)

Only the uppermost portion of the Chemung group crops out in the Bradford quadrangle. The outcrops are along the lower stretches of Tunungwant Valley and its tributaries. The following section in the Penn Brick Corporation's shale quarry No. 1 in the city of Bradford (loc. 2, pl. C), shows the characteristics of this portion:

	Feet
Interbedded greenish-gray shale and fine-grained sandstone, fossiliferous	38.9
Greenish-gray fine-grained sandstone, fossiliferous	3.0
Bluish-gray sandy shale	9.3
Interbedded bluish-gray sandy shale and shaly sandstone	13.7
Bluish-gray fine-grained sandstone	1.4
Bluish-gray shale	4.5
Bluish-gray fine-grained sandstone, fossiliferous	.6
Bluish-gray sandy shale, fossiliferous	8.7

The following fossils were identified by Charles Butts in a collection made by Paul D. Torrey at this locality in 1926: *Spirifer disjunctus*, very abundant; *Productella lachrymosa*, common; *Camarotoechia contracta*, common. Inasmuch as these fossils are characteristic of the entire Chemung section, they are of no close stratigraphic significance. The appearance of the upper Chemung is shown in Plate 7A, which represents the face exposed in the abandoned quarry of the Hanley Company just south of the above quarry (loc. 3, pl. C).

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[62] Charles Butts, Geologic section of Blair and Huntingdon Counties, Central Pennsylvania: Am. Jour. Sci., 4th ser., vol. 46, 1918, p. 535.

[63] Charles Butts. Description of the Warren Quadrangle. Folio No. 172, U. S. Geological Survey, 1910, page 4.

[64] John F. Carll, The geology of the oil regions: Pennsylvania Second Geol. Survey, Report I 3, 1880, p. 130.

The upper Chemung shales have been extensively utilized in the past at the localities mentioned for making common red building and face brick. In recent years, however, the plants have not been active.

Attention must be called to the fact that the upper beds in the Chemung group in the Bradford district are younger than the Chemung beds of the type locality around the sides of Narrow Hill, at Chemung Narrows west of Chemung in south-central New York. This necessarily follows since, as has been pointed out, the Catskill type of sedimentation, of which the Cattaraugus represents only the last stage, began progressively earlier as one goes eastward. This relationship has been recently emphasized by Chadwick.[65] It is quite probable, therefore, that after a thorough restudy of the upper Devonian stratigraphy of New York and Pennsylvania has been completed, it will be found advisable to segregate the above beds from the Chemung under a separate grouping, as Chadwick has proposed.

SUBSURFACE FORMATIONS

WELL RECORDS

BRADFORD DISTRICT

Inasmuch as only a very small percentage of the oil produced in the Bradford field has come from sands other than the Bradford Third and no troublesome water-bearing strata are present, it has not been customary to keep as careful records of the formations drilled through as in fields having more than one productive horizon. Rarely are the depth and thickness of non-productive sands recorded. Among the thousands of well records obtained in connection with the present investigation, only a relatively small number yielded any information other than the depth to the top and bottom of the Bradford Third sand, the total depth drilled, and the amount of casing used. The position of such important and readily recognizable horizon markers as the base of the Olean and the top and bottom of the Cattaraugus red beds is rarely shown in the driller's logs. During the field work, however, this information was obtained for many wells by actual observation on nearby outcrops. From over 5,000 records examined, 266 which contained the most information were selected for correlation purposes. These have been compiled in Table 3. The locations of the wells are shown on Plate D. They are numbered in consecutive order from west to east in strips one mile wide starting at the north. The elevations, which were taken either on the derrick floor or, where this had been removed, on its estimated position, are believed to be accurate within two feet.

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[65] George H. Chadwick, The stratigraphy of the Chemung group in western New York: New York State Mus. Bull. 251, 1924, p. 154.
Great Catskill Delta (Upper Devonian Revision in New York and Pennsylvania): Pan-American Geologist, vol. 60, 1933, pp. 281-286.
Chemung is Portage. Bull. Geol. Soc. America, vol. 46, pp. 343-354, 1935.

Table 3. Selected Well Records, Bradford District

Map Number	1	2	3	4	5	6	7
Owner	South Penn Oil Co.	Nichol Run Oil Co.	Nichol Run Oil Co.	N.V.V. Franchot	Miller Bros. and Bovaird	E. F. Curtis	Bradford Producing Co.
Property and well number..........	Coast 18	Cochran 130	Cochran 52	Hollander 25	Lippert Hollow 13	Kimball 11	Mayrock K-19
Elevation	2074	2300	2209	1823	2277	2340	2096
Drive pipe				69			
Casing	369	8¼″ 380 6¼″ 1234		420		420	305
Bottom of Olean	279 feet above top of well				7 feet above top of well	16	
Top of Cattaraugus	100 feet above top of well			279 feet above top of well		208	
Sands:— Bradford First							
Sugar Run							
Chipmunk	Stray 1213-1261	1411-1454 oil	1334-1358				1107-1135
Bradford Second		gas 1530-1545 oil 1545-1582	1476-1491 oil				1262-1318
Harrisburg Run							
Bradford Third	1608-1628 oil		1769-1789	1345-1425 oil	Top 1795 oil	1855-1914 oil	1581-1635 oil
Lewis Run (4th)							
Kane (5th)							
Haskell (6th)							
Total Depth	1654	1617	1820	1513		1993	1656

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	8	9	10	11	12	13	14
Owner	Bradford Producing Co.	Downs, Hane and Co.	H. A. and G. W. Hooker	Nichol Run Oil Co.	Nichol Run Oil Co.	Nichol Run Oil Co.	Nichol Run Oil Co.
Property and well number	Mayrock 1-Squires	Lot 1, No. 2	G. B. Forman 2	Pinkerton 4	Pinkerton 11	Pinkerton 8	Hough 91
Elevation	1644		1877	2020	2254	1962	2246
Drive pipe							
Casing	275	317	325	300	335	275	8¼″ 338 6¼″ 1191
Bottom of Olean							
Top of Cattaraugus		230					171
Sands:— Bradford First				Top 915	Top 1190 salt water		
Sugar Run		1363-1381	1042-1074				
Chipmunk				1139-1164 oil	1364-1400 oil	1077-1125	1368-1387 oil
Bradford Second		1522-1528 salt water		1265-1307	1481-1542 oil	1207-1232 oil	1447-1517 oil
Harrisburg Run							
Bradford Third	1172-1192 oil 1210-1230 1247-1267		1545-1560 oil	1573-1604	1804-1813	1510-1530	1788-1804
Lewis Run (4th)						1578-1605	
Kane (5th)						1805-1819 a little gas	
Haskell (6th)							
Total Depth	1282	1528	1675		1845	2426	1829

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	15	16	17	18	19	20	21
Owner	Nichol Run Oil Co.	Kendall Refining Co.	Kendall Refining Co.	Ryder and Richmond Oil Co.	Kinley Oil Co.	Forest Petroleum Corp.	Messer Petroleum Corp.
Property and well number	Cochran 76	Dana 17	Dana 16	State Line 34-F	No. 30	Sims B-05	Mersereau 14
Elevation	2239	2381	2359	2097	2353	2345	1640
Drive pipe							
Casing		442	428	352	422	485	300
Bottom of Olean		55				32	
Top of Cattaraugus				34 feet above top of well	241		
Sands:— Bradford First		1235-1265					
Sugar Run							
Chipmunk	1367-1383						676-694 show of oil
Bradford Second	1500-1524 oil		1550-1570				
Harrisburg Run		Top 1650					
Bradford Third	1784-1797	1893-1990	1868-1949	1620-1700	gas 1860-1891 oil 1891-1931	gas 1846-1872 oil 1872-1906	1095-1170 oil
Lewis Run (4th)							
Kane (5th)							
Haskell (6th)							
Total Depth	1817	2100	2016	1707	1978	1950	1221

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	22	23	24	25	26	27	28
Owner	Mix Creek Oil Co.	Wood and Associated Producers Co.	Downs, Hane and Co.	F. G. Hane	P. C. Stack	John Becker	P. Hooker Estate
Property and well number	No. 166	Warrant 4335,Kent 1	Warrant 4335, No. 2	Lot 54 No. 1	Jas. Stack 4	No. 2	No. 9
Elevation					1718	1460	1416
Drive Pipe				60		100	255
Casing	505		420	350	240	330	333
Bottom of Olean							
Cattaraugus			317-600				
Sands:—							
Bradford First		Top 784	1294-1318				
Sugar Run		1445-1482					
Chipmunk		Stray 1120-1150	Top stray 1565		920-960	650-700 show of oil	592-650
Bradford Second		1159-1186 gas	1616-1625 gas	Top 1064			
Harrisburg Run			1420-1440				785-800 stray 920-925
Bradford Third	1094-1138 oil			No Bradford	1368-1394 oil	1085-1120 oil	1025-1040 oil
Lewis Run (4th)		1622-1661					
Kane (5th)							
Haskell (6th)	a little gas in stray at 1924	Stray 1899-1916					
Total Depth	3250	1926	1625	1500	1410	1120	1058

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	29	30	31	32	33	34	35
Owner	P. Hooker Estate	Johnston and Matthews	F. M. Johnston and Son	F. M. Johnston and Son	Kendall Refining Co.	Kendall Refining Co.	Kendall Refining Co.
Property and well number	No. 8	McCune 1	No. 66	No. 107	Mixer 13	Mixer 10	Hatch 56
Elevation	1418	1597	1715	1790	1842	1837	2263
Drive pipe	250						
Casing	330	286	374	442	459		360
Bottom of Olean							
Cattaraugus							
Sands:—							
Bradford First					702-728		
Sugar Run					825-832 851-863 874-893		1250-1270
Chipmunk	590-611 oil			Stray 933-958	Stray 991-1017		
Bradford Second		840-870			1051-1077		1475-1525
Harrisburg Run			985-1006	1058-1078 oil	1086-1147	1096-1143	
Bradford Third		1174-1194 oil	1232-1294 oil		1350-1418 oil	1345-1400 oil	1780-1842 oil
Lewis Run (4th)							
Kane (5th)							
Haskell (6th)							
Total Depth	660	1230	1309	1102	1526	1473	1862

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	36	37	38	39	40	41	42
Owner	Kendall Refining Co.	Messer Oil Co.	T. H. Colligon	Johnston and Matthews	Foster Oil Co.	Johnston and Matthews	Johnston and Matthews
Property and well number	Albro 11	Loop 19	Grant 8	Hanna and Clark 7	Hinchey 1 Discovery	Hanna and Clark 10	Hanna and Clark 13
Elevation	2264	1732	1485	1437		1426	1422
Drive pipe		48	84	229		256	243
Casing		290	354	475		523	300
Bottom of Olean							
Top of Cattaraugus	201						
Sands:— Bradford First				435-450 salt water	442-460	Top 435 salt water	
Sugar Run						510-560 saft water	
Chipmunk		Top 750	702-760 show of oil	650-670 show of oil		635-660 show of oil	630-650
Bradford Second		Top 900			750-780 show of oil		
Harrisburg Run							
Bradford Third	1775-1850 oil	1189-1258	1108-1131 oil	1042-1070 oil	1100-1130 oil 1136-1206	1031-1049 oil	1025-1054 oil
Lewis Run (4th)							
Kane (5th)							
Haskell (6th)							
Total Depth		1296	1177	1088	1595	1079	1076

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	43	44	45	46	47	48	49
Owner	E. E. Bryner and Sons	E. E. Bryner and Sons	Kendall Refining Co.	Kendall Refining Co.	Kendall Refining Co.	Kendall Refining Co.	Rob Roy
Property and well number	Emery and Hamsher 29	Emery and Hamsher 40	Boyer Royalty 19	Boyer Fee 41	Boyer Fee 87	Wheeler 18	Red Rock 10
Elevation	1420	1421	1639	1657	1668	1808	
Drive Pipe	246	240	58	86	80		
Casing	360	445	265	370	378	174	216
Bottom of Olean							
Top of Cattaraugus							
Sands:— Bradford First			550–570	560–595			
Sugar Run		500–540 show of oil salt water	635–655	635–650	655–675	835–850	Top 896 salt water
Chipmunk		620–650		703–721	744–775		
Bradford Second	728-740 show of oil	725–750	860–900	860–878	860–900	1000–1040	
Harrisburg Run				1000–1020			
Bradford Third	1025–1063 oil	1012–1040 oil	1179–1248 oil	1182–1250 oil	1193–1270 oil	1329–1388 oil	1436-1480 oil
Lewis Run (4th)							
Kane (5th)							
Haskell (6th)							
Total Depth	1120	1073	1374	1350	1391	1530	1530

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	50	51	52	53	54	55	56
Owner	Bradford Producing Co.	North Penn Gas Co.	Albert O'Neill	S. L. Rhodes Estate	J. F. Rider	L. H. Smith and Sons	S. J. and R.H. George
Property and well number	Artley 74	No. 1	No. 1	No. 26	Boss 39	Lincoln 12	Lafferty Hollow 40
Elevation	1915	1710	1659	1583	1513	1723	1715
Drive pipe		60				43	
Casing	363	260		320	342	310	185
Bottom of Olean							
Top of Cattaraugus							
Sands:— Bradford First							
Sugar run		814-890 show of gas	816-829 show of gas				Top 800
Chipmunk				Stray 850-870			
Bradford Second		1000-1048 gas	950-984	886-906 oil	810-835	960-1055	955-1045
Harrisburg Run	1250-1260						
Bradford Third	1443-1499 oil	1373-1423	1340-1373 oil		1180-1222 oil	1314-1346 oil	1290-1330 oil
Lewis Run (4th)							
Kane (5th)							
Haskell (6th)							
Total Depth	1532	1423	2160	920	1254	1427	1385

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	57	58	59	60	61	61	63
Owner	Bradford Producing Co.	Sloan and Zook Oil Co.	Taylor Oil Co.	Pringle and Kearns	W. W. Brown Estate	W. W. Brown Estate	W. H. Emery
Property and well number	Mitchell Franks 8	Duke 57	No. 17	W. S. Sikes 12	No. 17	No. 7	Hatfield 22
Elevation	2095		1687	1614	1630	1677	1497
Drive pipe				44	40	125	160
Casing	320	212	273	290	274	220	390
Bottom of Olean							
Top of Cattaraugus	36						
Sands:— **Bradford First**					Top 646		
Sugar Run		830–845			Top 718 show of gas		
Chipmunk						940–964	
Bradford Second					oil 963–983 983–1015	1005–1037 oil	833–880
Harrisburg Run		1168–1186				Top 1125 show of gas	
Bradford Third	1641–1682 oil	1359–1400 oil	gas 1354–1361 oil 1386–1394 1401–1404 1415–1423	1290–1299 oil 1302–1312		1360–1389 oil	1160–1195 oil
Lewis Run (4th)		1470–1475 show of gas					
Kane (5th)							
Haskell (6th)							
Total Depth	1733	1476	1455	1352	1029	1389	1218

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	64	65	66	67	68	69	70
Owner	W. H. Emery	D. M. Edmunds	McIntyre	S. L. Rhodes Estate	C. P. Gildersleeve	D. M. Edmunds	S. L. Rhodes Estate
Property and well number	Foster 16	No. 25	No. 8	No. 25	No. 1	No. 3	No. 28
Elevation	1803	1466	1540	1509	1502	1609	1450
Drive pipe		134	75	55	77		204
Casing	350	410	240	342	358		439
Bottom of Olean							
Top of Cattaraugus	65 feet above top of well						
Sands:— Bradford First					Top 518		
Sugar Run							
Chipmunk							Stray 728–744
Bradford Second	1130-1170 show of oil	785-825	870-940	812-830 oil	838-868	938-965 oil	765-790
Harrisburg Run							
Bradford Third	1478–1510 oil	1101–1137 oil	1185–1217 oil	Top 1154 oil	1140–1186 oil		1100–1135 oil
Lewis Run (4th)							
Kane (5th)							
Haskell (6th)							
Total Depth	1521	1162		1209	1204	977	1157

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	71	72	73	74	75	76	77
Owner	J. B. Jamison	C. W. Dennis and Co.	Minard Run Oil Co.	L. H. Smith and Sons	Healey Petroleum Corp.	L. H. Smith and Sons	Frank Gould
Property and well number	No. 2	Roger 1	Dikeman 36	Lincoln 13	Powers 32	Lincoln 10	No. 2
Elevation	1612	2055	1443	1695	2116	1896	1502
Drive pipe			215				63
Casing	240		345	300	420	275	418
Bottom of Olean					100 feet above top of well		
Cattaraugus Top (T) Bottom (B)		T132 B382			T127		
Sands:—							
Bradford First	top 610	1056–1072 1077–1081 1088–1094		660–690	1081–1125		
Sugar Run		1111–1125 show of oil				970–988	Top 590
Chipmunk		stray 1300–1317					
Bradford Second	920-952	1345-1381	710-720 724-735 show of oil and salt water	940-1000	1350-1460	1147-1175	740-764
Harrisburg Run							
Bradford Third	1244-1289 oil	1664-1718 oil	1049-1085 oil	1284-1310 oil	1690-1726 oil	oil 1480-1517 1534-1542	1080-1139 oil
Lewis Run (4th)						Top 1577	
Kane (5th)							
Haskell (6th)							
Total Depth	1307	1719	1100	1400	1764	1640	1179

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	78	79	80	81	82	83	84
Owner	Wm. Healey and Co.	Wm. Healey and Co.	Sloan and Zook Producing Co.	Towne-Melvin Oil Co.	Petroleum Reclamation Co.	Sloan and Zook Producing Co.	Forest Oil Corp'n
Property and well number	Hunt 30	Van Scoy 25	Summit B-16	Smedley 47	North Looker K-17	Summit K-9	Tyler 64
Elevation	1740	1631	2263	2152	2128	1978	1853
Drive pipe	55	32					
Casing	365	342	351			275	253
Bottom of Olean							
Cattaraugus Top T, Bottom B				T 152	T 135 B 429		
Sands:— Bradford first			1205-1210				
Sugar Run	812-830	740-770			1175-1195	1030-1045	
Chipmunk			1400-1413		1278-1302		
Bradford Second	1000-1040 1060-1067	925-945	1485-1503		1372-1396		
Harrisburg Run					1466-1494 1502-1537	1331-1345	
Bradford Third	1346-1373 1388-1401 oil	1241-1263 1271-1280 oil	1816-1861 1886-1899 oil	1737-1765 1783-1797 oil	1707-1730 1748-1766	1546-1576 1600-1616 oil	1418-1437 1455-1462 oil
Lewis Run (4th)							1545-1553 gas
Kane (5th)							
Haskell (6th)							
Total Depth	1471	1373	1919	1831	1791	1661	1585

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	85	86	87	88	89	90	91
Owner	Bradford Producing Co.	Gridiron Oil Co.	L. L. Shoff	Bradford Producing Co.	Stover and Hannon	S. J. George	S. J. George
Property and well number	Hifler 0-20	No. 99	No. 1	Grow 48	Ellis 1	West Branch 58	West Branch 60
Elevation	1663	1605	1622	1721	1507	2126	2169
Drive pipe	57	95	47				
Casing	430	425	485	300		432	491
Bottom of Olean							9
Cattaraugus Top T, Bottom B					B 41		T 271
Sands:— Bradford First						1170-1195	
Sugar Run	710-730			900-920			
Chipmunk							
Bradford Second						1470-1518 oil and salt water	1502-1553 oil
Harrisburg Run	1070-1100						
Bradford Third	1248-1293 oil	1178-1229 oil	1269-1281 oil	1410-1421 1429-1442 oil	oil 1224-1236 1259-1272		
Lewis Run (4th)			1350-1357				
Kane (5th)							
Haskell (6th)		1657-1717 show of gas					
Total depth	1313	1721	1378	1470	1282	1518	1553

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	92	93	94	95	96	97	98
Owner	Jack and Jack	S. G. George	Forest Petroleum Corp.	Forest Petroleum Corp.	R. M. Clark	Petroleum Reclamation Co.	Wm. Healey and Co.
Property and well number	Cramer 9	West Branch 41	Niles 37	Niles 42	No. 20	Hawkins B-5	Hunt 51
Elevation	1585	1584	1509	1560	1488	2240	1783
Drive pipe			154		187		56
Casing	245	425	460	520	530		325
Bottom of Olean						55	
Cattaraugus						278-572	
Sands:— Bradford First		675-682 show of gas				1250-1290	
Sugar Run							848-860
Chipmunk							906-935
Bradford Second	960-979 show of oil salt water	894-982	858-868 oil	910-925 oil	832-865 oil	1528-1548	1074-1090
Harrisburg Run							
Bradford Third	1275-1305 1312-1338 oil	1260-1298		1225-1275 oil	1153-1178 oil	1846-1896 oil	1390-1432 oil
Lewis Run (4th)							
Kane (5th)							
Haskell (6th)							
Total Depth	1378	1349	889	1300	1193	1910	1512

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	99	100	101	102	103	104	105
Owner	Coit	S. H. Elder	Petroleum Reclamation Co.	T. H. Kennedy	Petroleum Reclamation Co.	Sloan and Zook Oil Co.	L. M. Lilly
Property and well number	No. 43	Corwin 1	West Looker 254	Summit 32	North Looker L-4	Sprague & Kenemuth A-1	Southard 11
Elevation	1917	1646		2189	1984	1548	1568
Drive pipe						115	40
Casing		304		305		500	365
Bottom of Olean							
Cattaraugus	Top 42 feet above top of well		158-486		B 325		
Sands:— Bradford First			1161-1182 1198-1209				
Sugar Run		778-808	1248-1280		1091-1099 1107-1132	690-710	
Chipmunk			1335-1345		1185-1222		
Bradford Second			1410-1430				
Harrisburg Run			1522-1549		1375-1392 1402-1430	950-970	
Bradford Third	1532-1564 oil	1296-1320 oil	1731-1752 1768-1791 oil	1792-1822 oil	1585-1652 oil	1221-1257 oil	Top 1310 very little sand
Lewis Run (4th)				1876-1888 1904-1922			
Kane (5th)							
Haskell (6th)							1775-1805 gas
Total Depth	1593	1325	1802	1938	1676	1281	1854

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	**106**	**107**	**108**	**109**	**110**	**111**	**112**
Owner		Bisett Brothers	Cochran and Connelly	Lewis Newell	H. L. Stoner	Lewis Newell	Lewis Newell
Property and well number	Warrant 3422	West Branch 52	No. 20	Balton 11	West Branch 10	Geddis 5	Balton 9
Elevation		1617	1616	1551	1551	1553	1545
Drive pipe				105	140	100	136
Casing	315	300	283	380	504	404	551
Bottom of Olean							
Cattaraugus							
Sands:—							
Bradford First		700-730	720-740		Top 625 a little salt water		
Sugar Run	1020-1058 show of oil					780-790 show of gas	
Chipmunk				880-890			
Bradford Second	1204-1235 dry. 1235-1260 show of oil salt water	1000-1030	1020-1060	930-968	948-960 show of oil		921-956 show of oil salt water
Harrisburg Run							
Bradford Third		1332-1356 oil	1323-1359 oil	1264-1286 oil	1268-1285 oil	1269-1308 oil	1256-1285 oil
Lewis Run (4th)							
Kane (5th)							
Haskell (6th)							
Total Depth	1260		1363	1337	1361	1355	1340

Table 3. Selected Well Records, Bradford District, Cont'd.

Map number	**113**	**114**	**115**	**116**	**117**	**118**	**119**
Owner		H. J. Nichols	Healey Petroleum Corp.	Minard Run Oil Co.	Minard Run Oil Co.	Carl Morris	Forest Petroleum Corp.
Property and well number	Crooker School Deep well		G-024	Cram 6	Stoddard 1	Griffin 29	Fisher 33
Elevation		1785	2175	1795	1578	1928	1802
Drive pipe	80						
Casing	340	380		212	256	477	456
Bottom of Olean			46				
Top of Cattaraugus				142 feet above top of well		37 feet above top of well	
Sands:— Bradford First		Top 830			Top 620		
Sugar Run		Top 975 show of gas					
Chipmunk		Top 1030					
Bradford Second		Top 1170			Top 880		
Harrisburg Run							
Bradford Third	1290–1324 oil	1487–1520 oil	1844–1883 oil	Top 1422 oil	1203–1240 oil	1543–1562 oil	1802–1837 oil
Lewis Run (4th)							1886–1892 1905–1919
Kane (5th)	1586–1601 slight show of gas						
Haskell (6th)							
Total Depth		1520	1883	1480	1286	1600	1939

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	**120**	**121**	**122**	**123**	**124**	**125**	**126**
Owner	Alice Freeman	Petroleum Reclamation Co.	Devore Oil Co.	Forest Petroleum Corp.	Associated Producers Co.	Associated Producers Co.	Petroleum Reclamation Co.
Property and well number	No. 11	Pratt Hollow Deep Well	No. 33	Fisher E-010	Connolly 6	Seil 1	South Looker 205
Elevation	1677		2010	1980		1850	
Drive pipe							
Casing	318	200	250	310	396	526	
Bottom of Olean							
Top of Cattaraugus				51			
Sands:— Bradford First		780–800					
Sugar Run						880–904 show of gas	
Chipmunk			1285–1325			1045–1085 show of gas	
Bradford Second		1090–1115					
Harrisburg Run							
Bradford Third	1335–1346 1363–1372 oil	1402–1417 1433–1438 oil	1668–1686 1704–1738 oil	1623–1647 oil	1710–1774 oil	1437–1460 oil	1253–1317 1335-1373 oil
Lewis Run (4th)	1424–1434 1470–1477	1498–1557					
Kane (5th)		1711–1766			1972 2032 show of oil	1712–1747 1767–1801	1538–1552 1567–1573 1581–1587
Haskell (6th)		1850–1905			2136–2185 show of gas	1897–1944 show of oil	1701–1707 1723–1738 show of gas
Total depth	1494		1771	1663	2218	1950	stray 1818–1851 1860

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	127	128	129	130	131	132	133
Owner	Messer Oil Corp.	W. C. Kennedy Co.	Bovaird and Enright	Kendall Refining Co.	Kendall Refining Co.	Hillside Oil Co.	T. F. Murphy
Property and well number	Breese A-1	Booth 41	Songbird Fee 56	Edmonds 17	Edmonds 12	Clapp 21	Degolia 7
Elevation	1730	1651	2195	1644	1623	1652	1504
Drive pipe		60		40	76		104
Casing	305	447	462	425	405	246	550
Bottom of Olean							
Top of Cattaraugus	205 feet above top of well B 106						
Sands:— Bradford First		745–765	1277–1300	665–680		Top 665	490–502
Sugar Run							
Chipmunk			1397–1483				
Bradford Second		1070–1089	1574–1620		958–969	Top 990	800–809
Harrisburg Run							
Bradford Third	1376–1420 oil	1364–1404 oil some salt water	1874–1930 oil	1282–1345 oil	1257–1307 oil	1287–1345 oil	1133–1166 oil
Lewis Run (4th)							
Kane (5th)							
Haskell (6th)							
Total depth	1446	1442	1945	1395	1410	1355	

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	134	135	136	137	138	139	140
Owner	E. E. Bryner and Sons	E. E. Bryner and Sons	E. E. Bryner and Sons	E. E. Bryner and Sons	Minard Run Oil Co.	L. H. Smith and Sons	J. Fred Lawson
Property and well number	Bryner and Martin 25	Orcutt 11	Strick 17	Orcutt 20	Moody 121	Passmore 5	Taylor 10
Elevation	1511	1497	1495	1482	2273	1763	
Drive pipe	184	147	180	180			
Casing	470	567	520	554	580	525	
Bottom of Olean					15		
Top of Cattaraugus							
Sands:— Bradford First							
Sugar Run		618-623		586–608 some salt water			
Chipmunk							1439–1465 show of oil
Bradford Second	827–835 a little salt water	808–824					
Harrisburg Run							
Bradford Third	1127–1158 oil	1125–1157 oil	1111–1136 oil	1111–1143 oil	1976–1989 oil 2023–2046	1438–1447 1473–1502 oil	1835–1883 oil
Lewis Run (4th)						1564–1574	
Kane (5th)							
Haskell (6th)			Top 1622 show of gas stray 1831–1837				
Total depth	1195	1200	2011	1143	2087	1624	1899

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	**141**	**142**	**143**	**144**	**145**	**146**	**147**
Owner	Suhr and McSweeney	G. L. Rhodes	Esther Oil Co.	Don T. Andrus	Don T. Andrus	Don T. Andrus	Burdick and Stover
Property and well number	No. 62	No. 14	No. 4	Duke and Harris 98	Duke and Harris 31	McGrew 68	Newell 27
Elevation	2018	1826	1943	1913		2171	1721
Drive pipe							42
Casing	260	285		260	313	420	342
Bottom of Olean						2	328 feet above top of well
Top of Cattaraugus	102			18			
Sands:— Bradford First							855–880
Sugar Run	Top 1160						
Chipmunk							
Bradford Second	Top 1290						1160–1175
Harrisburg Run							1275–1278 show of gas
Bradford Third	1647–1678 oil	1457–1501	Top 1570 oil	1572–1594 oil	1608–1633 oil	1842–1875 oil	1466–1493 oil
Lewis Run (4th)							
Kane (5th)							
Haskell (6th)		Top 1937 show of gas	2000–2040 gas		Top 2073 gas		
Total depth	1700	2050	2160	1607		1905	

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	148	149	150	151	152	153	154
Owner	Minard Run Oil Co.	Enright and Co.	Hungiville Bros.	Eagle Oil Co.	A. J. Foster	Bairy Estate	Rich and Co.
Property and well number	Bainsdall 6	McCafferty 9	No. 14	No. 5	Cross Roads Oil Co. 4	Deagan Fee 24	Cole 6
Elevation	1847	2208	1937	1718	1521	1581	1617
Drive pipe					104		129
Casing	221	427		330	750		516
Bottom of Olean							
Top of Cattaraugus	42 feet above top of well		17				
Sands: —							
Bradford First		Stray 664-696 salt water					
Sugar Run							796-802
Chipmunk							
Bradford Second				1040-1052			
Harrisburg Run							
Bradford Third	Top 1490 oil	1868-1904 oil	1568-1593 oil	1335-1357 oil	1150-1164 oil	1202-1218 oil	1312-1330 1341-1348 oil
Lewis Run (4th)				Top 1463		Top 1370 show of gas	1405-1410
Kane (5th)					Stray 1465-1516		
Haskell (6th)					1558-1563 show of gas		
Total Depth	1575	1923		1482	1563	1382	1417

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	155	156	157	158	159	160	161
Owner		J. H. Gibson & others	Walker Bros.	Bovaird and Hamlin	South Penn Oil Co.	S. H. Elder	Bouton Oil Co.
Property and well number	Edson 5	Lot 385 Thomas 16	Tack 5	Reco 41	Bingham Lot 396 H. E. Smith 35	Brown 17	C. C. Wright Estate 1
Elevation	1665		2242	2171	1906	1736	1629
Drive pipe							
Casing		400	368			367	438
Bottom of Olean			17				
Top of Cattaraugus					Top of Marvin Creek 8		
Sands:—							
Bradford First				1227-1255 1263-1288			
Sugar Run							
Chipmunk							1001-1041 show of oil
Bradford Second				1525-1534			
Harrisburg Run							
Bradford Third	1412-1422 oil	1980-2010 2013-2020 oil	1921-1966 oil	1836-1872 oil	1620-1645 oil	1403-1441 oil	1445-1458 show of gas 1496-1516
Lewis Run (4th)	1476-1482 show of oil						
Kane (5th)		2260-2285					
Haskell (6th)		2425-2445 show of gas				1843-1854 gas	Top 1886
Total Depth	1487	2515	1974	1898	1666	1903	2100

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	162	163	164	165	166	167	168
Owner	McConnell Oil Co.	Minard Run Oil Co.	George W. Moore	Lewis Run Mfg. Co.	Beechwood Oil Co.	Fessenmyer and Rapp	W. T. Collins
Property and well number	Beecher 3	Venture Oil Co. Brown Lot 2	No. 86	No. 30	No. 19	Eymer 1	No. 19
Elevation	2250		2234	2073	2233	1695	1599
Drive pipe							61
Casing	330	400	315	400	390	386	410
Bottom of Olean							
Top of Cattaraugus							
Sands:— Bradford First		Top 1255					Pink rock 350-1400 a little water
Sugar Run							
Chipmunk	Top 1445			1245-1255	1435-1445		
Bradford Second		1550-1575			1608-1615		
Harrisburg Run	1665-1693 show of oil					Top 1100	
Bradford Third	1925-1972 oil	1846-1906 oil and salt water	1903-1977 oil	1723-1754	1911-1942 oil	1352-1365 oil	1225-1238 oil
Lewis Run (4th)		2000-2004	2069-2073 show of gas	1867-1874		1467-1470 1513-1518 show of gas	
Kane (5th)		Stray Top 2155					
Haskell (6th)		2280-2290					
Total Depth	1997	2303	2650	1900	1960	1539	1267

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	**169**	**170**	**171**	**172**	**173**	**174**	**175**
Owner	G. W. Foster	C. S. Dieter	Friedman	Bryner and Emery	Bryner and Emery	H. B. Cannon	Alumina Shale Brick Co.
Property and well number	McMann 9	No. 1	Kelly 1	Lafayette Mfg. Co. 1	Lafayette Mfg. Co. 2	No. 2	No. 2
Elevation	1584	1558	1527	1548	1549	1560	1660
Drive pipe		178	165	130	145	83	
Casing	520	537	470	325	436	330	306
Bottom of Olean							
Cattaraugus Top T, Bottom B	B 36 feet above top of well					T 310 feet above top of well	
Sands:— Bradford First			Top 594				
Sugar Run			Top 620 show of gas and salt water				
Chipmunk			Top 670				
Bradford Second			Top 850	895-924 oil	891-916	920-940 show of oil	1055-1085
Harrisburg Run				967-971		985-987	
Bradford Third	1219-1240 oil	1183-1198 oil	1154-1169 oil		1230-1236 1260-1266	1240-1260	1373-1394
Lewis Run (4th)	1335-1341 show of gas	1305-1308	1261-1276		1327-1335 gas	1332-1339 show of gas	1462-1471 gas
Kane (5th)							
Haskell (6th)							
Total Depth		1330	1284	979	1435	1360	1490

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	176	177	178	179	180	181	182
Owner	Alumina Shale Brick Co.	Minard Run Oil Co.	Minard Run Oil Co.	T. H. Kennedy	J. A. Hooper	Lewis Run Mfg. Co.	W. C. Kennedy and Co. and F. D. Wood
Property and well number	No. 1	Moody 142	Moody 206	Connolly 113	Lot 432 No. 3	No. 29	Lewis Run 55
Elevation	1638	1665	1820	2157	1762	2181	1606
Drive pipe		53	48				47
Casing	297	338	525	434	370	342	390
Bottom of Olean				41 feet above top of well			
Top of Cattaraugus					2		
Sands:—							
Bradford First						1295-1335	
Sugar Run							
Chipmunk					Top 1156	1435-1470 gas	890-902 a little gas
Bradford Second						1595-1939	1020-1118 show of gas and salt water
Harrisburg Run	1082-1085	1122-1128	Stray 1466-1476				
Bradford Third	1347-1368	1380-1405 good show of oil	1599-1640 oil	Top 1917 oil	Top 1573 oil	1895-1939	1371-1391 salt water and show of oil
Lewis Run (4th)	1436-1442 gas	1464-1475	1700-1710 show of oil				1452-1459 oil
Kane (5th)		Stray 1515-1533	1880-1903				
Haskell (6th)			Stray 1993-1999				
Total Depth	1454	1933	2001	1970	1622		1477

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	183	184	185	186	187	188	189
Owner	Lewis Run Mfg. Co.	W. C. Kennedy & Co. and F. D. Wood	W. C. Kennedy & Co. and F. D. Wood	Minard Run Oil Co.	Minard Run Oil Co.	South Penn Oil Co.	H. G. Barcroft
Property and well number	No. 22	Lewis Run 48	Lewis Run 52	Moody 147	Moody 211	Moody Lot 66, No. 21	Moody Lot 57, No. 8
Elevation	1634	1605	1608	1661	1628	1763	1830
Drive pipe		55		110	182	55	59
Casing	240	419	581	510	618	354	325
Bottom of Olean							
Top of Cattaraugus						Top of Marvin Creek limestone. 14 feet above top of well	
Sands:— Bradford First	725-785						
Sugar Run					810-840		
Chipmunk		888-900 a little salt water	892-904				
Bradford Second	1025-1040	1020-1100	1022-1120	1140-1170	1069-1100		
Harrisburg Run							1460-1510 slight show of oil
Bradford Third	1325-1330	1364-1384 show of oil	1370-1390 salt water	1431-1448	1360-1372 1380-1390	1615-1646 oil	1662-1699 oil
Lewis Run (4th)	1430-1443 gas	1448-1454 oil and some salt water	1458-1464 oil	1513-1520 oil	1478-1487 oil		
Kane (5th)				Stray 1734-1755			
Haskell (6th)							
Total Depth	1484	1478	1490	1772	1537	1651	1730

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	190	191	192	193	194	195	196
Owner	Grant and Mohan	Grant and Mohan	T. H. Kennedy	J. A. Hooper	Lewis Run Mfg. Co.	W. C. Kennedy & Co. and F. D. Wood	W. C. Kennedy & Co. and F. D. Wood
Property and well number	Moody Lot 56, No. 61	Bingham Lot 473 No. 14	Connolly 53	Lot 432 Gas Well	No. 8	Lewis Run 41	Lewis Run 29
Elevation	2026	2213	1694	1670	1789	1782	1611
Drive pipe							88
Casing	360	390	650	376	400	356	577
Bottom of Olean	54 feet above top of well	Upper Marshburg coal 11 feet above top of well			365 feet above top of well		
Top of Cattaraugus							
Sands:— Bradford First							
Sugar Run				960-972 gas			
Chipmunk					1067-1087 gas	1065-1080 a little gas	915-922
Bradford Second						1200-1260	1015-1100 a little gas
Harrisburg Run							
Bradford Third	1852-1888 oil	2017-2053 oil	1492-1532 oil	Top 1480 salt water show of oil	1548-1569	1540-1560 salt water	1390-1411 salt water
Lewis Run (4th)	1960-1972				1633-1643 oil	1638-1644 oil and salt water	1468-1476 oil
Kane (5th)	Stray 2132-2173 2204-2219 show of gas		1742-1757		Stray 1685-1705		
Haskell (6th)			Stray 1860-1866 stray top 2070				
Total Depth	2295		2100	1940	1797	1661	1490

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	**197**	**198**	**199**	**200**	**201**	**202**	**203**
Owner	W. C. Kennedy & Co. and F. D. Wood	Bovaird and Canan	A. E. Booth	Bovaird and Canan	J. Diem	C. P. Byron Estate	C. P. Byron Estate
Property and well number	Schwab 26	2-W	Dent 4	No. 7	Bannon 2	Stoney Point 27	Stoney Point 9
Elevation	2139		1654	1702		2111	1879
Drive pipe		72	154	85			
Casing	610	400	610	720		428	
Bottom of Olean	65						
Top of Cattaraugus							Top of Marvin Creek limestone 41
Sands:—							
Bradford First		950-1000	Top 960				
Sugar Run		1050-1070					
Chipmunk	1610-1710						
Bradford Second		1245-1285					
Harrisburg Run	Stray 1940 Stray 1994-2000		Top 1264				
Bradford Third	2017-2025 oil	1539-1578 oil	1529-1559 oil	1574-1601 oil	2025-2048 oil	1968-2035 show of oil	1730-1745 oil
Lewis Run (4th)							
Kane (5th)	2248-2267 show of oil		1780-1804 show of oil	1841-1866		Top 2236 gas	
Haskell (6th)	Stray 2324-2334 Stray 2402-2416 show of oil		Stray 1861-1868	Stray 1901-1917	Stray 2346-2363 oil		
Total Depth	2435	1583	1915	1927	2371	2262	1745

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	204	205	206	207	208	209	210
Owner	Moody and Moody	Associated Producers Co.	Associated Producers Co.	Associated Producers Co.	Associated Producers Co.	Associated Producers Co.	Associated Producers Co.
Property and well number	No. 21	Johnston 5 Lot D	Bingham 390	Bingham 87	Bingham 137	Bingham 371	Bingham 188
Elevation	2170	2031	2150	2154	2219	2171	2173
Drive pipe							
Casing	403	393	486			350	
Bottom of Olean		40 feet above top of well					
Cattaraugus			460-780			490-830	
Sands:— Bradford First							
Sugar Run			1452-1480 1510-1521			1438-1476 1491-1498	
Chipmunk			1571-1610			1538-1588 small show of oil	
Bradford Second	1787-1812						
Harrisburg Run							
Bradford Third	2096-2109 show of oil	1902-1945 oil	2004-2051 oil	1988-2036 oil	2040-2085 oil	1997-2034 oil	2015-2067 oil
Lewis Run (4th)							
Kane (5th)				2279-2309 good show of gas and oil	2288-2306 2328-2360 gas		2293-2320 gas
Haskell (6th)							
Total Depth	2542	1945	2051	2309	2360	2034	2552

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	**211**	**212**	**213**	**214**	**215**	**216**	**217**
Owner	C. P. Byron Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.
Property and well number	Cyclone 9	No. 1017	No. 1012	No. 1011	No. 1022	No. 2448	No. 2512
Elevation	2130	2132	2097	2050	2161	2107	2050
Drive pipe							
Casing	334						
Bottom of Olean							
Top of Cattaraugus							
Sands:— Bradford First							
Sugar Run							
Chipmunk						1622-1628	
Bradford Second						1733-1798 gas	1610-1624
Harrisburg Run							1715-1726 gas
Bradford Third	1989-2018 oil	2030-2071	2011-2036	1974-1982	2098-2127	2030-2040	1974-1994
Lewis Run (4th)							Stray 2148-2181
Kane (5th)	2261-2284	2280-2304	2225-2269	2211-2225	2331-2342	2249-2261 gas	2193-2205 gas
Haskell (6th)							
Total Depth	2284	2326	2269	2225	2342	2293	2247

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	218	219	220	221	222	223	224
Owner	United Natural Gas Co.	Minard Run Oil Co.	Jas. F. Magee	Associated Producers Co.	Associated Producers Co.	Associated Producers Co.	Associated Producers Co.
Property and well number	No. 2082	Dent 56	Bowen 3	Johnston 48	Johnston 158	Johnston 78	Bingham 370
Elevation	2189	1956	2092	2098	2119	2073	2162
Drive pipe							
Casing		465		398	392	367	351
Bottom of Olean		9	Alton coal 26 feet above top of well			13 feet above top of well	
Cattaraugus							465-780
Sands:—							
Bradford First							1450-1480
Sugar Run	1602-1614						1512-1521
Chipmunk							1572-1612
Bradford Second							
Harrisburg Run							
Bradford Third		1910-1928 oil	2024-2042	1978-2044 oil	1998-2041 oil	1936-1975 oil	2021-2050
Lewis Run (4th)							
Kane (5th)	2312-2320			Stray Top 2315	2262-2291	Top 2210	
Haskell (6th)							
Total Depth	2345	1957	2658		2291		2050

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	225	226	227	228	229	230	231
Owner	Associated Producers Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.
Property and well number	Bingham 182	No. 1013	No. 1035	No. 2611	No. 1037	No. 2012	No. 2679
Elevation	2168	2099	2134	2154	2177	2176	2178
Drive pipe							
Casing							
Bottom of Olean						99	
Top of Cattaraugus							
Sands:— Bradford First							
Sugar Run							
Chipmunk							
Bradford Second							
Harrisburg Run							
Bradford Third	2019-2067 oil	2059-2102	2050-2056	2078-2094 gas		2075-2100	
Lewis Run (4th)							
Kane (5th)	2289-2339 gas	2275-2316	2249-2277 gas	2279-2316	2273-2286 gas	2259-2273	2246-2252 gas
Haskell (6th)				2482-2527 gas			2515-2530
Total Depth	2339	2504	2303	2541	2311	2274	2539

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	**232**	**233**	**234**	**235**	**236**	**237**	**238**
Owner	United Natural Gas Co.	United Natural Gas Co.	W. S. Weed and Co. Devonian Oil Co.	Berwald and Odell Oil Co.	Johnston and Matthews	Johnston and Matthews	United Natural Gas Co.
Property and well number	No. 2042	No. 2197	Warrant 3410 Glenn Charles Well	No. 1	Bingham 68-R	Bingham 97-J	No. 1028
Elevation	2176	2190		1906	2093	2121	2220
Drive pipe							
Casing							
Bottom of Olean				77 feet above top of well			
Top of Cattaraugus							
Sands:— Bradford First			1140-1170				
Sugar Run							
Chipmunk							
Bradford Second							
Harrisburg Run			1471-1500 a little gas at top	1616-1648 show of oil			
Bradford Third			1741-1785 slight show of oil	1857-1871 show of oil salt water	2010-2040 oil	2014-2044 oil	2136-2153
Lewis Run (4th)							
Kane (5th)	2293-2304 gas	2297-2307 gas	2045-2075 very slight show of oil		2290-2307	2285-2305	2336-2350
Haskell (6th)							
Total Depth	2330	2452	2178	1871	2323	2330	2381

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	239	240	241	242	243	244	245
Owner	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.
Property and well number	No. 1029	No. 999	No. 1034	No. 1031	No. 1033	No. 1036	No. 1038
Elevation	2162	2145	2145	2054	2160	2127	2110
Drive pipe							
Casing							
Bottom of Olean							
Top of Cattaraugus							
Sands:— Bradford First							
Sugar Run							
Chipmunk				1500-1530			
Bradford Second							
Harrisburg Run							
Bradford Third	2042-2060 gas	Top 2067	2050-2063 gas	1935-1949	2019-2028		
Lewis Run (4th)							
Kane (5th)	2239-2255	2265-2281 gas		2126-2138	2209-2211	2192-2203 gas	2179-2190 gas
Haskell (6th)					2462-2472		
Total Depth	2279	2373	2063	2442	2631	2252	2241

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	246	247	248	249	250	251	252
Owner	J. W. Bouton	E. E. Bryner and Sons	Johnson and Henline	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.	United Natural Gas Co.
Property and well number	Haskell 1	James 8	Johnson 61	No. 1018	No. 1019	No. 1032	No. 2846
Elevation	1527	2042	1993	2150	2147	2142	2200
Drive pipe							
Casing	250	393	364				
Bottom of Olean			36 feet above top of well				
Top of Cataraugus							
Sands:— Bradford First	660-680						
Sugar Run	716-719 show of oil						
Chipmunk	780-785					1600-1630	
Bradford Second							
Harrisburg Run	1030-1045						
Bradford Third	1245-1263 smell of oil	2009-2033		2077-2082	2060-2066		2075-2094
Lewis Run (4th)	1345-1357 show of oil						
Kane (5th)	1480-1482 show of oil	2214-2241 show of oil	2145-2183 oil	2267-2280	2252-2270	2237-2247	2264-2283
Haskell (6th)	1718-1736 oil				Stray 2447-2474	Stray 2434-2471	
Total Depth	1861	2241		2311	2505	2476	2330

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	253	254	255	256	257	258	259
Owner	United Natural Gas Co.	J. W. Bouton	J. W. Bouton	J. W. Bouton	W. C. Kennedy and Co.	Emery and Simpson	C. L. Baker
Property and well number	No. 2691	Comes 2	Van Sickle 7	McDowell 1	Lot 137 Lafayette 7	No. 38	No. 2
Elevation	2182	1609	1662	1561	1886	2014	2104
Drive pipe							
Casing			300	293	341	338	375
Bottom of Olean							
Top of Cattaraugus		212 feet above top of well					
Sands:— **Bradford First**				700-730			
Sugar Run							Top 1520 show of gas
Chipmunk							1595-1600
Bradford Second							Top 1725
Harrisburg Run							Stray 1973-1980
Bradford Third	2060-2075 gas	Top 1346 oil	1398-1413 oil	1292-1304 oil	1792-1866 oil	1938-1982 oil	2038-2103 salt water
Lewis Run (4th)			1464-1472	1370-1390			
Kane (5th)	2250-2270 gas		Stray Top 1718	Stray 1620-1640	2037-2092	2170-2184 some gas 2213-2229 gas	2281-2290 2307-2314 gas
Haskell (6th)			1854-1866 oil	1745-1757 oil			
Total depth			1883		2190	2259	2325

Table 3. Selected Well Records, Bradford District, Cont'd.

Map Number	260	261	262	263	264	265	266
Owner	H. L. Stoner	Demps Petroleum Gas Co.	Demps Petroleum Gas Co.	Johnson and Henline	Test Oil Co.	Hulings and Guffey	W. C. Kennedy & Co. and F. W. Wood
Property and well number	Irons Estate 1	P. Newell 10	Cork 35	Johnson 98	Patterson 10	Hulings 3 Warrant 3076	Oakes 31
Elevation	1542	1624	1975	2069		1715	
Drive pipe	63						51
Casing	525	296	460	420			325
Bottom of Olean			46 feet above top of well	101			
Cattaraugus Top (T)		T 19	T 355			150-420	
Sands:— Bradford First		964-999	1374-1378				
Sugar Run						1110-1125	
Chipmunk					1275-1320 gas		
Bradford Second	937-943	1264-1289				Top 1375	
Harrisburg Run			1637-1655			1450-1465	
Bradford Third	1284-1300	1564-1600	1906-1961		Top 1696-1729, oil salt water 1750	1665-1730 show of oil salt water	1852-1890
Lewis Run (4th)							
Kane (5th)				2230-2260 oil			2037-2045 2065-2075 salt water
Haskell (6th)							
Total Depth	1313	1600			1750	1730	2075

The early drillers in the Bradford field thought that the oil came from the same geological horizon as that occupied by the "Third Sand" along Oil Creek in Venango County.[66] An upper sand, about 600 feet above the producing horizon, was therefore called the "First Sand" and a lower one, about 300 feet above the same horizon, the "Second Sand." This nomenclature has become firmly established among operators in the field in spite of the fact that the Bradford Third sand in the Bradford field actually lies 1250 feet below the horizon of the Venango Third sand. In order to avoid confusion, the First, Second and Third sands of the Bradford district are, therefore, referred to as the Bradford First, Second, and Third, respectively, to distinguish them from the Venango group of sands. Whenever the term Bradford sand is used without further qualifying adjective, the Bradford Third sand, the main producing horizon, is the one that is meant. The horizons referred to as the Bradford First and Second sands, respectively, in the Bradford district, do not correspond in stratigraphic position to the producing horizons known as First and Second Bradford sands in southwestern Pennsylvania[67]. Sisler states that the Bradford Third sand of the Bradford district corresponds approximately in stratigraphic position to the Third Bradford in the other oil and gas fields of the State[68]. The writer, thus far, has not had an opportunity to verify this correlation.

Some well records show two additional sands between the Bradford First and Second. The upper one of these corresponds in stratigraphic position to the Sugar Run sand, which has yielded considerable quantities of oil along Sugar Run in the vicinity of Klondike in Corydon Township, McKean County, west of the Bradford pool proper. The other represents the horizon of the Chipmunk sand, the oil-bearing sand in the Chipmunk pool, in Carrollton and Allegany Townships, Cattaraugus County, New York, north of the Bradford pool.

Between the Bradford Second and Third sands another sandstone is sometimes encountered which is frequently mistaken for the Bradford Second, although it lies about 100 feet below it. Some oil has been obtained from this sand in several wells near the head of Harrisburg Run in Foster Township, McKean County. The name Harrisburg Run is, therefore, proposed for it.

In wells drilled below the horizon of the Bradford sand, three additional sands are commonly recognized. The upper of these is usually referred to as the Lewis Run sand because it has yielded both oil and gas in the vicinity of Lewis Run, south of the city of Bradford. The second has been correlated by the drillers with the Kane sand of the Kane field in southwestern McKean and adjacent parts of Elk County, a correlation which is in agreement with the writer's own observations. The third is known as the Haskell sand because oil was encountered in it in the Haskell well drilled in 1877 on the east side of Marvin Creek, southwest of Smethport. The well was still producing in 1929. Ashburner called this horizon the Smethport oil

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[69] Chas. A. Ashburner, The Geology of McKean County: Pennsylvania Second Geol. Survey, Report R, 1880, p. 284.

[67] J. French Robinson, Stratigraphy of Southwestern Pennsylvania: Proceedings, Eng. Soc. Western Pennsylvania, vol. 46, 1930, p. 137.

[68] James D. Sisler, Correlation of oil and gas sands in Pennsylvania: Pennsylvania State College Min. Ind. Exper. Sta Bulletin 9, 1930, p. 16.

sand[69] but the latter name never came into general use. The three sands below the Bradford are sometimes also referred to locally as the Fourth, Fifth, and Sixth, respectively.

All the above nine sandstone horizons occur in the Chemung (Chautauquan) group of the Devonian system. No commercial production of oil or gas has thus far been encountered in the Bradford district below the horizon of the Haskell sand.

Northwest-southeast and southwest-northeast cross sections through the Bradford district constructed from data appearing in Table 3 are shown on Plate 8. The locations of these sections are given on Plate D. It will be noted that the Bradford Third sand is the most persistent sandstone in the area covered by the sections. All the others are markedly lenticular. While this characteristic of the Chemung (Chautauquan) sands is somewhat exaggerated in the sections, owing to the fact that sands other than the Bradford Third are so often not recorded in the driller's logs, the examination of complete sets of samples of drill cuttings from several wells, which supplemented the study of the large number of available well records, has led the author to the conclusion that actual conditions are essentially as represented in the sections.

The intervals between the base of the Olean, the top and bottom of the Cattaraugus red beds, and the important sandstones of the Chemung (Chautauquan) group, respectively, and the top of the Bradford Third sand in the Bradford district are summarized in Table 4. The figures given are derived from data presented in Table 3. The interval between the base of the Olean and the top of the Bradford Third sand is smallest in the northern part of the district and largest in the southern; that between the top of the Cattaraugus red beds and the top of the Bradford Third, on the other hand, is largest in the extreme northeastern part and smallest in the southwestern part; and that between the bottom of the Cattaraugus and the top of the Bradford Third is smallest in the northeastern part.

Table 4. Intervals between important horizons and the top of the Bradford Third Sand in the Bradford District.

	Average interval feet	Minimum interval feet	Maximum interval feet
Base of Olean	1895	1791	1979
Top of Cattaraugus red beds	1575	1507	1708
Bottom of Cattaraugus red beds	1255	1183	1282
Top of sands:			
Bradford First	610	560	658
Sugar Run	525	483	559
Chipmunk	440	384	484
Bradford Second	325	284	390
Harrisburg Run	230	178	271
Bradford Third	0	0	0
Lewis Run (4th)	100	64	168
Kane (5th)	240	184	309
Haskell (6th)	450	408	511

McKEAN COUNTY AND ADJACENT AREAS

In order to show the stratigraphic position of the productive horizons of the Bradford district with respect to those of the other oil and gas pools in McKean County and adjacent areas, 48 typical well records have been se-

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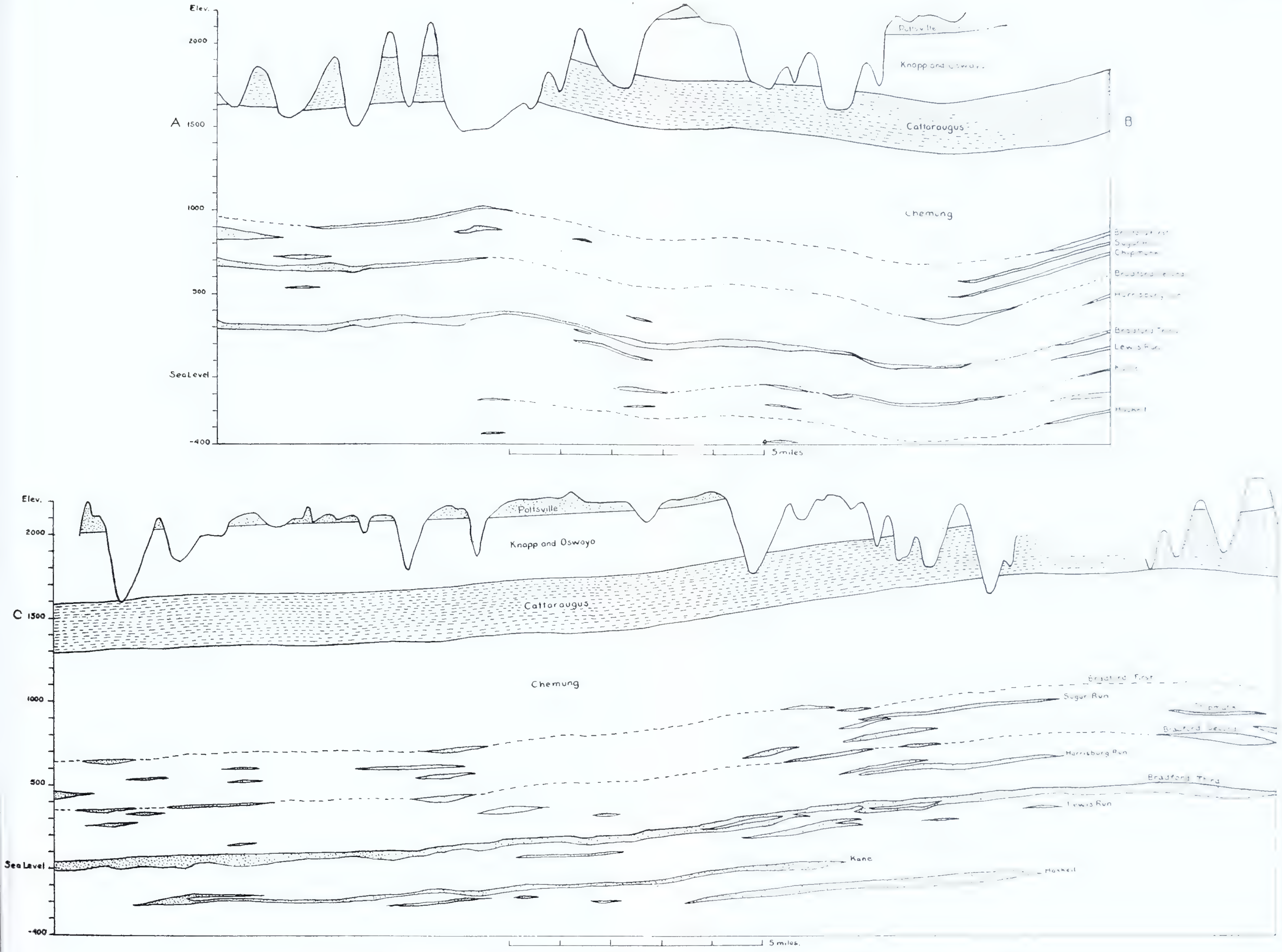
[69] Chas. A. Ashburner, The Geology of McKean County: Pennsylvania Second Geol. Survey Report R, 1880, p. 274.



Northwest-southeast and southwest-northeast sections through Bradford District.

lected covering practically all of McKean County and adjacent parts of Elk, Forest, Potter and Warren Counties, Pennsylvania, and Allegany and Cattaraugus Counties, New York. These have been numbered from 1 to 48,

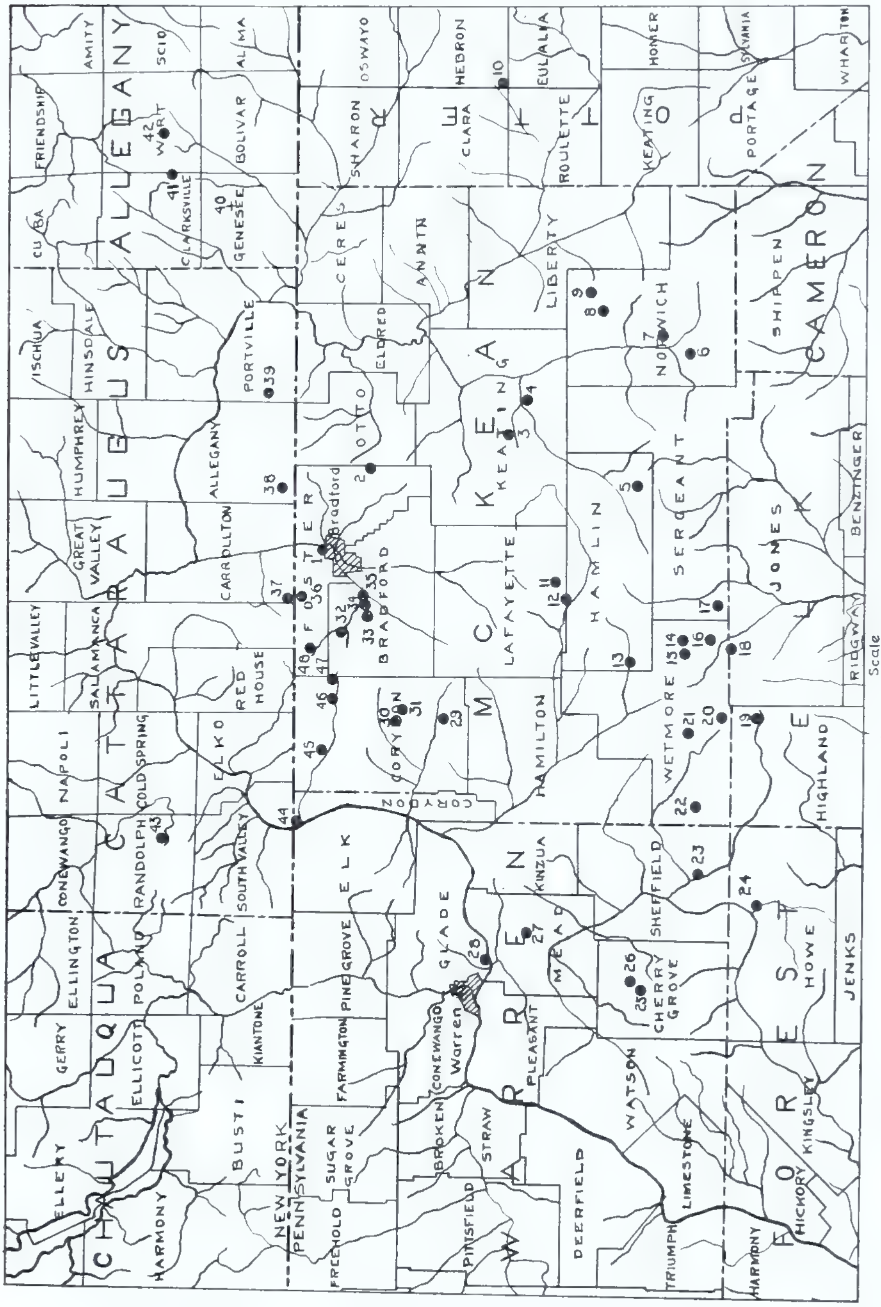


FIGURE 4. **Map of McKean County and adjacent areas showing location of selected wells**

respectively. The locations of the wells are shown in Figure 4. The records in consecutive order are given below. Correlations enclosed in parentheses are those of the writer.

No. 1. FOSTER WELL, No. 1 (Discovery well, 1871), Hinchey farm, Foster Township, McKean County. Authority, C. H. Foster. (Same as No. 40, Table 3.)

	Depth in feet Top	Bottom
Bradford First sand	442	460
Bradford Second sand	750	780
Bradford Third sand	1100	1130
Slate	1130	1136
Hard sandstone	1136	1206
Slate with occasional shells	1206	1595

No oil or gas below Bradford Third sand. Well deepened from 1136 feet to 1595 feet in 1873.

Record obtained from Report I-4, Pennsylvania Second Geological Survey, 1883, page 87.

NO. 2. PETROLEUM RECLAMATION COMPANY'S WEST LOOKER NO. 254 WELL. Foster Township, McKean County. (Same as No. 101, Table 3.)

Thickness feet	Description of strata	Depth in feet Top	Bottom
40	No samples	0	40
32	Very fine-grained greenish-gray argillaceous sandstone containing considerable muscovite mica	40	72
44	Greenish-gray sandy shale	72	116
4	Very fine grained reddish-brown argillaceous sandstone, fossiliferous	116	120
9	Fine-grained light greenish-gray sandstone, calcareous	120	129
7	Bluish-gray shale	129	136
2	Light-gray limestone, very fossiliferous (Marvin Creek)	136	138
14	Fine-grained light-gray sandstone containing carbonized plant remains and marine fossils	138	152
6	Light greenish-gray sandy shale, fossiliferous	152	158
	Top of Cattaraugus formation	158	
5	Brick-red shale	158	163
10	Light grayish-green shale with interbedded reddish-brown shale	163	173
22	Reddish-brown to brick-red shale	173	195
11	Very fine grained light greenish-gray sandstone, somewhat calcareous	195	206
6	Brick-red sandy shale	206	212
6	Very fine grained brick-red sandstone	212	218
27	Brick-red sandy shale	218	245
6	Greenish-gray sandy shale	245	251
5	Brick-red sandy shale	251	256
17	Greenish-gray sandy shale	256	273
39	Brick-red sandy shale, micaceous	273	312
6	Greenish-gray sandy shale	312	318
12	Greenish-gray shale	318	330
5	Dark brownish-red sandy shale, micaceous	330	335
6	Dark greenish-gray sandy shale, micaceous	335	341
12	Very fine grained dark greenish-gray sandstone, micaceous	341	353
10	Fine-grained brownish-gray sandstone, micaceous and calcareous	353	363
10	Fine-grained greenish-gray sandstone, calcareous	363	373
11	Fine-grained dark brownish-gray sandstone, micaceous	373	384
5	Brownish-gray sandy shale, micaceous	384	389
31	Greenish-gray sandy shale	389	420
12	Very fine grained light greenish-gray sandstone	420	432
12	Brick-red shale	432	444
6	Dark brownish-red sandy shale	444	450
19	Light greenish-gray sandy shale, micaceous	450	469
6	Brick-red shale	469	475
11	Gray shale with a little interbedded brick-red shale	475	486
	Top of Chemung group	486	
6	Greenish-gray sandy shale	486	492
11	Gray to dark greenish-gray shale	492	503
37	Gray sandy shale and shale, sparingly fossiliferous	503	540
13	Greenish-gray sandy shale, fossiliferous	540	553
6	Very fine grained light greenish-gray sandstone, fossiliferous and somewhat calcareous	553	559
85	Greenish-gray sandy shale with interbedded gray shale, fossiliferous	559	644
7	Dark grayish-purple and brown shale	644	651
6	Dark gray shale, fossiliferous	651	657
6	Dark greenish-gray sandy shale, fossiliferous	657	663

Thickness feet	Description of strata	Depth in feet Top	Bottom
7	Grayish-purple shale	663	670
7	Dark gray shale	670	677
105	Greenish-gray sandy shale, fossiliferous	677	782
16	Very fine grained light greenish-gray sandstone, fossiliferous	782	798
49	Greenish-gray sandy shale with interbedded gray shale, sparingly fossiliferous	798	847
17	Very fine grained greenish-gray sandstone, fossiliferous and slightly calcareous	847	864
27	Greenish-gray sandy shale	864	891
14	Very fine grained greenish-gray sandstone, fossiliferous	891	905
7	Gray shale	905	912
13	Very fine grained light grayish-brown sandstone, somewhat calcareous	912	925
236	Gray shale with a little interbedded greenish-gray shale, sparingly fossiliferous	925	1161
	Top of Bradford First sand	1161	
21	Very fine grained brownish-gray sandstone, fossiliferous sand somewhat calcareous	1161	1182
16	Gray shale	1182	1198
11	Very fine grained chocolate-brown sandstone	1198	1209
	Bottom of Bradford First sand		1209
39	Gray shale	1209	1248
32	Very fine grained grayish-brown sandstone, fossiliferous (Sugar Run)	1248	1280
55	Gray shale	1280	1335
10	Very fine grained light brownish-gray sandstone (Chipmunk)	1335	1345
65	Gray shale	1345	1410
20	Very fine grained brownish-gray sandstone, somewhat calcareous (Bradford Second sand)	1410	1430
92	Gray shale	1430	1522
27	Very fine grained light grayish-brown sandstone (Harrisburg Run)	1522	1549
181	Gray shale, sparingly fossiliferous	1549	1730
1	Very fine-grained light-gray sandstone, calcareous and fossiliferous	1730	1731
	Top of Bradford Third sand	1731	
21	Fine-grained chocolate-brown sandstone with a little interbedded gray shale	1731	1752
16	Gray shale with a little interbedded fine-grained chocolate-brown sandstone	1752	1768
23	Fine-grained chocolate-brown sandstone with a little interbedded gray shale	1768	1791
	Bottom of Bradford Third sand		1791
11	Gray shale	1791	1802
	Total depth		1802

The above detailed record is based upon the examination of a complete set of samples of the drill cuttings taken for the writer by the Petroleum Reclamation Company.

NO. 3. UNITED NATURAL GAS COMPANY'S NO. 2012 WELL. April 16, 1911. Ormsby Field, Keating Township, McKean County. (Same as No. 230, Table 3.) Elevation, 2176 feet.

	Depth in feet Top	Bottom
Base of Olean		99
Bradford Third sand	2075	2100
Kane sand	2259	2273
Total depth		2294

Initial production, 497,000 cubic feet of gas. Rock pressure, 575 pounds. Record obtained from United Natural Gas Company.

NO. 4. HASKELL WELL. 1877. On east side of Marvin Creek, about 1½ miles southwest of Smethport, McKean County. (Same as No. 246, Table 3.) Elevation, 1527 feet. (Obtained in 1929.)

	Depth in feet Top	Bot.
Conductor	0	30
Flagstone	30	55
Blue slate	55	220
Hard sand shells	220	245
Blue slate	245	420
Red shales	420	445
Blue slate	445	467
Red shale	467	479

	Depth in feet Top	Bot.
Hard shells and blue slate	479	500
Hard blue rock	500	502
Soapstone and shells	502	605
Very hard blue shales	605	615
Soapstone and hard shells	615	660
Sand, open and porous (Bradford First)	660	680
Soapstone and hard shells	680	716

	Depth in feet Top	Depth in feet Bot.
Pebble sand and gas (Sugar Run)	716	719
Soapstone and shells	719	780
Hard gray sand (Chipmunk)	780	785
Soapstone and shells	785	885
Soft white slate	885	920
Slate and shells	920	960
Very hard shell	960	965
Very soft soapstone	965	972
Very hard sand shells	972	975
Slate and shell	975	1030
Stray sand (Harrisburg Run)	1030	1045
Slate and shell	1045	1085
Hard sand shell	1085	1089
Good stray sand	1089	1093
Slate and shell	1093	1170
Second sand (not in agreement with writer's correlation)	1170	1215
Slate and shell	1215	1245
Stray sand (Bradford Third)	1245	1263
Soapstone and shell	1263	1345
Sand, show of oil (Lewis Run)	1345	1357
Soapstone shells	1357	1450
Shelly sand	1450	1457
Soapstone and shells	1457	1480
Shell, strong gas (Kane)	1480	1482
Soapstone shells	1482	1620
Sand, good show of oil (Betula)	1620	1650
Hard shells & sandy slate	1650	1713
Soapstone	1713	1718
Oil sand (Haskell)	1718	1736
Shells and sandy slate	1736	1861
Total depth		1861

Cased at 250 feet. Gas at 719. Strong gas at 1482 and 1620. Smell of oil at 1263. Show of oil at 1357, 1482, and 1620.

The above well, now owned by J. W. Bouton of Smethport, was still producing small quantities of oil from the Haskell sand in 1929. Ashburner called the sand occurring at 1345 to 1357 feet the Bradford Third. Since that correlation was made, the Ormsby and several small pools along Marvin Creek above the Haskell well have been opened up which have furnished considerable additional information for correlating the sands encountered in the Haskell well with those of the Bradford pool. This has led the writer to the conclusion that the sand encountered at 1245 to 1263 feet represents the Bradford Third horizon and the sand called the "Bradford Oil Sand" by Ashburner represents the Lewis Run. Ashburner called the Haskell sand the "Smethport Oil Sand" in his report but this name never came into general use. The name Betula is proposed for the sand occurring at a depth of 1620 to 1650 feet in the Haskell well as it corresponds in stratigraphic position to a sand encountered in the Betula gas pool in southeastern McKean County where commercial gas production is sometimes obtained from it.

Record obtained from Report R, Pennsylvania Second Geol. Survey, 1880, pp. 273-274.

NO. 5. UNITED NATURAL GAS COMPANY'S NO. 3618 WELL. June 10, 1924. Warrant No. 2365, Halsey Field, Hamlin Township, McKean County. Elevation, 2036 feet.

	Depth in feet Top	Depth in feet Bot.
Clay	0	25
Shale	25	30
Sand	30	50
Shale	50	85
Sand - water	85	100
Fire clay	100	110
Shale	110	353
Red rock	353	359
Water sand	359	364
Shale	364	370
Water sand	370	375
Slate	375	385
Second red rock	385	674
Sand	680	691
Slate	691	945
Slate and shells	945	1010
White sand	1010	1030
Pink rock and shells	1030	1222
Sand	1222	1242
Slate and shells	1242	1310
Limestone shells	1310	1422
Sand	1422	1430
Red rock, medium-grained sandstone composed of partially rounded quartz grains coated with hematite	1430	1442
Sand shell	1442	1500
Lime and sand	1500	1732
Lime and slate	1732	1822
Sand, light gray	1822	1842
Lime and slate	1842	1970
Sand—fine-grained, dark grayish-brown (Bradford Third)	1970	1988
Slate	1988	2026
Sand—fine-grained, grayish-brown, somewhat calcareous (Lewis Run)	2026	2047
Slate	2047	2195
Sand—fine-grained, grayish-brown, somewhat calcareous (Kane)	2195	2205
Slate	2205	2285
Sand—fine-grained, grayish-brown, calcareous (Betula)	2285	2337
Total depth		2337

Show of gas in Lewis Run, gas in Kane, and show of gas and considerable salt water in Betula. Initial production, 41,000 cubic feet. Rock pressure, 100 pounds.

Record obtained from United Natural Gas Company.

NO. 6. UNITED NATURAL GAS COMPANY'S NO. 1583 WELL. Betula (or Clermont) Field, Norwich Township, McKean County. Elevation, 2245 feet.

	Depth in feet Top	Bot.
Sand	1503	1524
Gas sand	1850	1868
Sand, a little gas	1974	1982
Sand, a little gas	2130	2140
Sand, a little gas	2178	2186
Sand, gas (Bradford Third)	2372	2378
Sand (Lewis Run)	2474	2494
Sand (Betula)	2684	2694
Sand	2775	2780
Break (Haskell)	2780	2795
Sand	2795	2800
Total depth		2820

Initial production, 25,000 cubic feet.
Record obtained from United Natural Gas Company.

NO. 7. UNITED NATURAL GAS COMPANY'S NO. 3644 WELL. August 29, 1924. Betula (or Clermont) Field, Norwich Township, McKean County.

	Depth in feet Top	Bot.
Red rock		260
Salt sand	394	414
Pink rock	750	775
Stray sand	1228	1243
Bradford Sand (Bradford Third)	1584	1619
Stray oil sand, fine-grained, very dark brown, show of oil and gas (Lewis Run)	1745	1753
Sand, fine-grained, brown, gas (Haskell)	2074	2124
Total depth		2206

Initial production, 52,000 cubic feet. Rock pressure, 635 pounds.
Record obtained from United Natural Gas Company.

NO. 8. UNITED NATURAL GAS COMPANY'S NO. 3796 WELL. Warrant 3796, Colegrove (Clermont) Field, Norwich Township, McKean County.

Thickness feet	Description of strata	Depth in feet Top	Bottom
30	Fine to medium-grained light greenish-gray sandstone	0	30
5	Bluish-gray shale	30	35
5	Fine-grained bluish-gray shaly sandstone	35	40
5	Bluish-gray shale	40	45
15	Fine-grained greenish-gray sandstone	45	60
20	Bluish-gray shale, fossiliferous	60	80
5	Fine-grained greenish-gray sandstone, contains carbonized plant fragments	80	85
20	Bluish-gray shale	85	105
5	Fine-grained light greenish-gray sandstone	105	110
9	Bluish-gray sandy shale, fossiliferous	110	119
24	Fine-grained light greenish-gray sandstone	119	143
24	Greenish-gray sandy shale, fossiliferous	143	167
10	Fine-grained light greenish-gray sandstone, fossiliferous and somewhat calcareous	167	177
10	Fine-grained greenish-gray shaly sandstone, fossiliferous	177	187
15	Greenish-gray shale	187	202
5	Fine-grained light greenish-gray sandstone, fossiliferous	202	207
5	Greenish-gray shale	207	212
15	Fine-grained light greenish-gray shaly sandstone, fossiliferous	212	227
5	Dark greenish-gray sandy shale	227	232
5	Fine-grained light greenish-gray shaly sandstone, fossiliferous and calcareous	232	237
10	Medium-grained light greenish-gray sandstone, fossiliferous and somewhat calcareous	237	247
5	Fine-grained light greenish-gray shaly sandstone	247	252
53	Interbedded greenish-gray shale and sandy shale	252	305
11	Fine-grained greenish-gray sandstone containing plant fragments	305	316
29	Greenish-gray shale	316	345
5	Fine-grained greenish-gray shaly sandstone	345	350
30	Medium-grained light greenish-gray sandstone	350	380
	Top of Cattaraugus formation	380	
11	Red shale	380	391
6	Medium-grained light greenish-gray sandstone	391	397
28	Red shale	397	425
10	Medium-grained light greenish-gray sandstone	425	435
10	Greenish-gray shale	435	445
5	Purplish-red shale	445	450
20	Fine to medium-grained light greenish-gray sandstone	450	470

Thickness feet	Description of strata	Depth in feet Top	Bottom
5	Greenish-gray shale	470	475
5	Medium-grained light-gray sandstone	475	480
5	Greenish-gray shale	480	485
5	Medium-grained light greenish-gray sandstone	485	490
15	Red sandy shale	490	505
5	Medium-grained greenish-gray shaly sandstone	505	510
60	Red sandy shale and shale	510	570
5	Bluish-gray shale	570	575
23	Medium-grained light-gray sandstone	575	598
6	Red shale	598	604
11	Bluish-gray sandy shale and shale	604	615
13	Fine to medium-grained light-gray sandstone	615	628
72	Red shale, in part sandy	628	700
12	Purplish-red sandy shale	700	712
	Top of Chemung group	712	
24	Greenish-gray shale	712	736
18	Medium-grained light-gray sandstone containing carbonized plant fragments	736	754
6	Greenish-gray shale	754	760
12	Medium to coarse-grained light-gray sandstone containing quartz grains up to 2.5 mm. in diameter	760	772
18	Dark greenish-gray shale	772	790
13	Coarse-grained light-gray sandstone containing quartz grains up to 2.5 mm. in diameter	790	803
6	Dark greenish-gray shale	803	809
6	Medium-grained light greenish-gray sandstone	809	815
17	Dark greenish-gray shale	815	832
5	Fine-grained light greenish-gray sandstone	832	837
5	Dark greenish-gray shale	837	842
5	Fine-grained light greenish-gray sandstone	842	847
100	Dark greenish-gray shale with some interbedded greenish-gray sandy shale	847	947
6	Fine-grained light greenish-gray sandstone, somewhat calcareous	947	953
42	Dark greenish-gray shale with some interbedded light greenish-gray shaly sandstone	953	995
12	Fine-grained light-gray sandstone, somewhat calcareous	995	1007
6	Greenish-gray sandy shale	1007	1013
12	Dark greenish-gray shale	1013	1025
12	Fine-grained light greenish-gray sandstone	1025	1037
18	Greenish-gray sandy shale	1037	1055
37	Dark greenish-gray shale with some interbedded purplish-gray shale	1055	1092
29	Purplish-gray shale, in part sandy	1092	1121
54	Greenish-gray shale with some interbedded purplish-gray shale	1121	1175
7	Purplish-gray sandy shale, fossiliferous	1175	1182
94	Greenish-gray shale with a little interbedded purplish-gray sandy shale, sparingly fossiliferous	1182	1276
13	Purplish-gray shale	1276	1289
49	Greenish-gray shale, sparingly fossiliferous	1289	1338
5	Medium-grained light-gray sandstone	1338	1343
63	Greenish-gray shale	1343	1406
12	Fine-grained light greenish-gray to brownish-gray sandstone (Bradford First)	1406	1418
61	Greenish-gray shale	1418	1479
5	Medium-grained reddish-brown sandstone, somewhat calcareous	1479	1484
5	Fine-grained light greenish-gray sandstone	1484	1489
52	Greenish-gray shale with some interbedded greenish-gray sandy shale	1489	1541
5	Medium-grained light greenish-gray sandstone	1541	1546
18	Dark greenish-gray shale, fossiliferous in lower part	1546	1564
16	Fine-grained light greenish-gray sandstone, somewhat calcareous	1564	1580
24	Dark greenish-gray shale, fossiliferous	1580	1604
24	Fine to medium-grained light greenish-gray and brownish-gray sandstone	1604	1628
16	Greenish-gray sandy shale, fossiliferous	1628	1644
39	Dark greenish-gray shale	1644	1683
27	Fine to medium-grained light brownish-gray sandstone, calcareous	1683	1710
6	Greenish-gray shale	1710	1716
12	Fine-grained light greenish-gray and light brownish-gray sandstone, fossiliferous and calcareous	1716	1728

Thickness feet	Description of strata	Depth in feet Top	Botto
63	Greenish to dark greenish-gray shale, fossiliferous	1728	1791
11	Fine-grained light greenish-gray sandstone, fossiliferous and calcareous	1791	1802
48	Greenish-gray shale, fossiliferous	1802	1850
6	Fine-grained chocolate-brown sandstone, calcareous, show of oil	1850	1856
37	Greenish-gray shale, fossiliferous	1856	1893
2	Medium-grained light greenish-gray sandstone, somewhat calcareous	1893	1895
30	Dark greenish-gray shale, fossiliferous	1895	1925
19	Fine-grained light greenish-gray sandstone, fossiliferous and somewhat calcareous	1925	1944
6	Greenish-gray shale	1944	1950
6	Fine-grained light greenish-gray sandstone, fossiliferous and somewhat calcareous	1950	1956
40	Dark greenish-gray shale	1956	1996
	Top of Bradford Third Sand	1996	
6	Fine-grained chocolate-brown sandstone, fossiliferous	1996	2002
10	Greenish-gray shale	2002	2012
19	Fine-grained light chocolate-brown sandstone, fossiliferous	2012	2031
	Bottom of Bradford Third Sand (show of gas in this sand)		2031
10	Dark greenish-gray shale with a little interbedded fine-grained greenish-gray sandstone	2031	2041
77	Greenish-gray shale, fossiliferous	2041	2118
9	Greenish-gray sandy shale, fossiliferous	2118	2127
192	Greenish-gray shale	2127	2319
7	Fine-grained chocolate-brown sandstone (Betula)	2319	2326
103	Greenish-gray shale	2326	2429
	Top of Haskell sand	2429	
54	Fine-grained light chocolate-brown sandstone with some interbedded greenish-gray shale, gas	2429	2483
21	Greenish-gray shale with a little interbedded fine-grained dark chocolate-brown sandstone, fossiliferous	2483	2504
15	Fine-grained dark chocolate-brown shaly sandstone	2504	2519
5	Fine-grained chocolate-brown sandstone	2519	2524
	Bottom of Haskell sand		2524
14	Light greenish-gray sandy shale	2524	2538
14	Greenish-gray shale	2538	2552
	Total depth		2552

Initial production, 43,000 cubic feet.

The above detailed record is based upon the examination of a complete set of samples of the drill cuttings received from the United Natural Gas Company.

NO. 9. UNITED NATURAL GAS COMPANY'S NO. 3867 WELL. Colegrove (Clermont) Field, Norwich Township, McKean County. Elevation, 2194 feet.

	Depth in feet Top	Bot.
Soft sand	0	50
Sand	150	175
Red rock	416	508
Sand, white	508	532
Sand, red	532	560
Red rock	585	598
Red rock	615	668
Red rock	698	718
Red rock	740	754
Sand, white, hard	754	776
Sand, white	857	882
Pink rock	1217	1234

	Depth in feet Top	Bot.
Gray sand } (Bradford 1st)	1453	1497
Break } (Bradford 1st)	1497	1499
Gray sand } (Bradford 1st)	1499	1507
Sand	1570	1590
Oil sand, dry	1650	1695
Gray sand	1744	1772
Sand, show of gas (Bradford Third)	2072	2084
Sand (Betula)	2397	2421
Sand, show of gas (Haskell)	2516	2532
Total depth		2600

Record obtained from United Natural Gas Company.

NO. 10. POTTER DEVELOPMENT COMPANY'S A. MATTESON NO. 1 WELL. Southwest corner of Hebron Township, Potter County. (A detailed description of the strata penetrated by this well is given under No. 11 of the deep well records.)

NO. 11. EMERY AND SIMPSON'S NO. 38 WELL. February, 1929. Near Riterville, Lafayette Township, McKean County. (Same as No. 258, Table 3.) Elevation, 2014 feet.

		Depth in feet	
		Top	Bottom
Bradford Third sand, oil		1938	1982
Sand, some gas		2170	2184
Break	Kane sand	2184	2213
Sand, gas		2213	2229
Total depth			2259

Initial production, 175,000 cubic feet. Rock pressure, 750 pounds.
Record obtained from J. W. Simpson.

NO. 12. DEMPS PETROLEUM AND GAS COMPANY'S CORK NO. 35 WELL. August, 1929. Near Guffey, Lafayette Township, McKean County. (Same as No. 262, Table 3.) Elevation, 1975 feet.

	Depth in feet	
	Top	Bottom
Red rock	355	540
Pink rock	1145	1160
Bradford First sand	1374	1378
Sand (Harrisburg Run)	1637	1655
Bradford Third sand, oil	1906	1961

Top of well is located 46 feet below the base of the Olean sandstone.
Record obtained from R. A. Chisholm, driller.

NO. 13. KINZUA WELL. 1877. On the south branch of Kinzua Creek near the mouth of Glade Run. Warrant 3123. Hamlin Township, McKean County. Elevation, 1718 feet.

	Depth in feet	
	Top	Bot.
Surface clay, etc	0	32
Soft slate	32	110
Mud slate	110	205
Red rock	205	255
Slate rock	255	293
Red rock	293	350
Sand, shells and red rock mixed	350	365
Slate	365	400
Sand shell	400	410
Slate	410	756
Mixed slate and hard slate rock	756	1017

	Depth in feet	
	Top	Bot.
Mixed slate and sand shells	1017	1375
Hard slate mixed with sand and pebble shell	1375	1745
Sand, salt water (Bradford Third)	1745	1760
Slate break (Bradford Third)	1760	1768
Sand, salt water (Bradford Third)	1768	1780
Slate	1780	1785
Total depth		1785

Record obtained from Report I-4, Pennsylvania Second Geol. Survey of 1888, pages 112-113.

NO. 14. PAGE OIL COMPANY'S RALPH NO. R-8 WELL. 1929. Warrant 3172, Wetmore Township, McKean County.

	Depth in feet	
	Top	Bot.
Soil	0	15
Rock	15	45
Slate	45	86
Slate and sand	86	148
Slate and water sand	148	198
Slate	198	210
Sandy	210	225
Slate	225	235
Sand	235	240
Slate	240	252
Sand, hard	252	282
Slate	282	295
Lime ?	295	345
Slate	345	354
Lime ?	354	370
Slate	370	376
Sand	376	386
Lime ?	386	415
Sand	415	425
Slate	425	432
Lime ?	432	437
Sand	437	446
Slate	446	470
Sand	470	480
Slate	480	486
Sand	486	500

	Depth in feet	
	Top	Bot.
Slate	500	575
Red rock	575	730
Slate	730	739
Red rock	739	770
Shell and sand	770	799
Red rock	799	895
Slate	895	903
Lime ?	903	912
Slate	912	918
Shell	918	934
Slate	934	950
Shelly	950	960
Slate	960	1000
Pink rock	1000	1030
Slate	1030	1052
Pink rock	1052	1060
Slate and shell	1060	1082
Pink rock	1082	1130
Slate	1130	1159
Pink rock	1159	1200
Slate	1200	1210
Lime ?	1210	1225
Slate	1225	1233
Shelly	1233	1246
Pink rock	1246	1298
Lime ?	1298	1325

	Depth in feet	
	Top	Bot.
Red rock	1325	1335
Slate	1335	1406
Red rock	1406	1418
Slate	1418	1455
Red rock	1455	1462
Slate	1462	1480
Red rock	1480	1492
Slate	1492	1500
Shelly	1500	1540
Lime ?	1540	1548
Slate	1548	1565
Lime ?	1565	1570
Sand, hard, Bradford First	1570	1600
Shelly	1600	1616
Slate	1616	1624
Lime ?	1624	1640
Slate	1640	1685
Shell	1685	1692
Slate	1692	1710
Shell	1710	1717
Lime ?	1717	1752
Slate	1752	1760
Sand	1760	1768
Lime ?	1768	1795
Slate	1795	1805
Shelly sand, hard	1805	1815
Lime ?	1815	1866
Slate	1866	1890
Shell	1890	1897
Slate	1897	1930
Sand, Kanesholm	1930	1936
Slate	1936	1952
Shelly	1952	1959
Slate	1959	1990
Lime ?	1990	2023
Slate and shale	2023	2078
Lime ?	2078	2134
Sand, oil, Bradford Third	2134	2177
Total depth		2207

Record obtained from Wilson K. Page.

NO. 15. ASSOCIATED PRODUCERS COMPANY'S RALPH NO. 188 WELL. Warrant 3172, Wetmore Township, McKean County. Elevation, 2067 feet.

	Depth in feet	
	Top	Bottom
Bradford Third sand, oil	2095	2115
Sand (Lewis Run)	2257	2284
Sand (Kane)	2326	2389
Haskell sand—soft, very light brown, almost gray, dry	2554	2572
Total depth		2622

Record obtained from Associated Producers Company.

NO. 16. COBURN WELL. August, 1879. On East Branch of Dalson Run, Warrant 3212, Wetmore Township, McKean County. Elevation, 1900 feet.

	Depth in feet	
	Top	Bot.
Conductor	0	20
White pebbly sand	20	70
Gray slate	70	102
Sand (show of oil)	102	148
Slate	148	178
Sand (show of oil)	178	212
Hard shell and sand	212	395
Red rock	395	595
Gray sand, containing gas	595	610
Red rock	610	710
Gray slate and shell	710	1240
Hard sand	1240	1256
Gray slate	1256	1380
Sand (Bradford First)	1380	1415
Gray slate	1415	1478
Sand (Sugar Run)	1478	1493
Gray slate	1493	1537
Sand (smell of oil)	1537	1557
Sand (nearly solid)	1557	1757
Gray slate	1757	1795
Sand	1795	1810
Gray slate	1810	1840
Sand	1840	1880
Gray slate and shells	1880	1944
Brown sand containing oil (Bradford Third)	1944	1953
Gray slate and shells (Bradford Third)	1953	1968
Sand	1968	2038
Slate	2038	2093
Slate and sand, gas at 2093	2093	2263
Total depth		2263

Record obtained from Report R, Pennsylvania Second Geol. Survey, 1880, page 243.

NO. 17. WILCOX WELL NO. 3. June, 1877, Warrant 2676, Sergeant Township, McKean County. Elevation, 1666 feet.

	Depth in feet	
	Top	Bot.
Alluvium	0	43
Gray slate	43	80
Gray sand	80	117
Red shale	117	145
Gray sand rock	145	155
Red shale	155	180
Gray slate	180	205
Red shale	205	325
Gray slate, sand and shell	325	355
Red slate	355	380
Gray slate	380	395
Gray slate and shell	395	415
Gray sand	415	430
Gray slate	430	435
Gray sand rock	435	442
Clover seed rock	442	450
Gray shale	450	465
Dark-gray slate and shell	465	547
Gray slate	547	665
Hard dark-gray shale	665	695
Gray slate and sand	695	700
Hard gray sand	700	715
Light sand with shale	715	720
White and gray sand	720	805
Gray slate	805	815
Fine gray sand	815	838

	Depth in feet	
	Top	Bot.
Red slate (pink rock)	838	845
Gray sand	845	870
Red slate (pink rock)	870	880
Gray slate	880	915
Red slate (pink rock)	915	920
Gray slate	920	935
Gray and white sand	935	965
Gray sand and slate	965	970
Fine hard dark-gray sand	970	975
Red slate (pink rock)	975	980
Gray slate	980	1015
Hard gray sand	1015	1035
Gray slate	1035	1070
Dark-gray and gray sand	1070	1080
Gray shale	1080	1095
Gray sand and very hard shells	1095	1100
Soft gray sand (Bradford First)	1100	1115
Gray and white sand (Bradford First)	1115	1125
Close soft white sand (Bradford First)	1125	1145
Hard gray shells	1145	1165
Gray slate	1165	1180
White and gray sand, coarse to fine with white pebbles (Sugar Run)	1180	1235
Gray slate and shell	1235	1245
Gray slate	1245	1285
Gray slate and shell	1285	1310
Gray and white sand	1310	1340
Slate	1340	1345
Gray and white sand, coarse to fine	1345	1370
Slate and hard shell	1370	1415
Gray slate	1415	1435
Slate and shell	1435	1440
Hard gray and white sandstone	1440	1455
Gray slate	1455	1490
Hard gray shale	1490	1495
Gray and white sand	1495	1510
Gray slate	1510	1530
Gray slate and shell	1530	1535
Hard white sand	1535	1545
Gray shell	1545	1550
Gray slate	1550	1575
Gray sand and shell	1575	1590
Gray slate	1590	1605
Gray sand	1605	1625
Gray slate and shell	1625	1685
Dark sand containing oil (Bradford Third)	1685	1705
Loose slate	1705	1715
Light colored slate	1715	1780
Dark sand — some gas (Lewis Run)	1780	1792
Light colored slate (Lewis Run)	1792	1808
Fine red and white sand (Lewis Run)	1808	1843
Sandy slate	1843	1850

Record obtained from Report R, Pennsylvania Second Geol. Survey, 1880, pages 162 to 166.

NO. 18. ERNHOUT AND TAYLOR WELL NO. 2. May 9, 1878. Southeast corner Warrant 3215, Wetmore Township, McKean County. Elevation (barometric), 1730 feet.

	Depth in feet	
	Top	Bot.
Loam and sand	0	40
Gray slate	40	125
Shells	125	135
Gray slate	135	200
Gray slate and shells	200	305
Red shale	305	315
Sand and shells	315	355
Red shale	355	480
Shells	480	510
Red rock	510	560
Gray slate	560	590
Red shale	590	645
Gray slate	645	820
Hard sand shells	820	900
Sand shell	900	1000
Sand	1000	1075
Red rock (pink rock)	1075	1080
Red rock, "pale" (pink rock)	1080	1085
Gray slate	1085	1170
Red Rock (pink rock)	1170	1175
Soft, muddy, gritty slate	1175	1305
Gray slate	1305	1385
Light gray slate	1385	1395
Sand shells	1395	1405
Sand, smell of oil (Sugar Run)	1405	1415
Sand containing heavy gas "veins" (Sugar Run)	1415	1417
Sand (Sugar Run)	1417	1422
Gray slate	1422	1470
Sand and shells	1470	1555
dark and light gray slate	1555	1765
Sandy slate	1765	1810
Hard gray sand	1810	1815
Slate	1815	1880
Dark-brown sand (Bradford Third)	1880	1890
Soft gray slate	1890	1980
Dark sand strongly impregnated with oil (Lewis Run)	1980	1990
Dark fine sand containing oil and salt water (Lewis Run)	1990	2000
Total depth		2000

The writer is of the opinion that the sand encountered at a depth of 1880 to 1890 feet represents the Bradford Third. Ashburner correlated the one struck at 1980 feet with this horizon.

Record obtained from Report R, Pennsylvania Second Geol. Survey, 1880, pages 244 - 246.

NO. 19. UNITED NATURAL GAS COMPANY'S NO. 3737 WELL. Warrant 3788, Highland Township, Elk County. A detailed description of the strata penetrated by this well is given under No. 10 of the deep well records.

NO. 20. PENNSYLVANIA GAS COMPANY'S NO. 675 WELL. Warrant 3754, Wetmore Township, McKean County.

	Depth in feet	
	Top	Bot.
Red rock	545	870
Pink rock	975	1340
Sand (Glade)	1492	1520
Sand (Cherry Grove)	1658	1680
Sand (Bradford Third)	2058	2079
Sand (Lewis Run)	2178	2200
Break (Lewis Run)	2200	2215
Sand (Lewis Run)	2215	2240
Sand, gas (Kane)	2303	2365
Total depth		2505

Record obtained from The Sloan and Zook Company.

NO. 21. THE SLOAN AND ZOOK COMPANY'S ACME NO. 54 WELL. Lot 420, Wetmore Township, McKean County.

	Depth in feet	
	Top	Bot.
Red Rock	334	500
Red rock shell	520	541
Second red rock	630	660
Pink rock	760	1127
Sand (Glade)	1320	1358
Sand (Clarendon)	1430	1460
Sand (Cooper)	1600	1634
Sand (Bradford Third)	1904	1914
Sand (Lewis Run)	2101	2148
Sand, oil (Kane)	2222	2292
Total depth		2292

Record obtained from The Sloan and Zook Company.

NO. 22. PENNSYLVANIA GAS COMPANY'S NO. 1108 WELL. January, 1930. Near middle of line between Lots 391 and 414, Wetmore Township, McKean County.

	Depth in feet	
	Top	Bot.
Red rock	668	693
Red rock	725	785
Red rock	925	950
Pink rock	1035	1397
Sand (Glade)	1692	1720
Sand (Cherry Grove)	1830	1845
Sand, oil (Cooper)	1962	1992
Total depth		2008

Record obtained from Pennsylvania Gas Company.

NO. 23. MAGEE AND HORTON NO. 1 WELL. April, 1881. Eastern part Lot 408, Sheffield Township, Warren County. Elevation (barometric), 1355 feet.

	Depth in feet	
	Top	Bot.
Drive pipe	0	85
Sandstone	85	135
Red rock	135	235
Sandstone, dark gray; salt water	235	275
Red rock	275	315
Slate and shale, cased at 385 feet., salt water at 400 feet	315	715
Sandstone, "good"	715	755
Slate and shale	755	1085
Sandstone, "good" (Glade)	1085	1110
Slate and sand shells	1110	1200
Sandstone, small pebbles, gas (Clarendon)	1200	1220
Slate and sand shells	1220	1385
Soft slate, white	1385	1400
Sandstone, white, quartz; oil and gas (Sheffield)	1400	1435

Initial production about 50 barrels per day.

Carll, on Plate 2, gives the following section, measured nearby:

Sandstone, Olean	40 feet
Concealed	180 "
Sandstone, Sub Olean	35 "
Concealed to top of well	195 "

Record obtained from Report I-4, Pennsylvania Second Geol. Survey, 1883, pages 25 - 26.

NO. 24. BLUE JAY NO. 1 WELL. November, 1880. At Foxburg, Howe Township, Forest County. Elevation (barometric), 1270 feet.

	Depth in feet	
	Top	Bot.
Conductor (drive pipe)	0	36
Not recorded	36	75
Sandstone, gray	75	90
Sandstone, gray, fine, hard	90	95
Slate	95	125
Red rock, very red	125	250
Sandstone, gray, fine, hard	250	260
Slate, cased at 287 feet	260	295
Sandstone, gray, finest and hardest in well	295	300
Slate	300	535
Sandstone, dark, shading on chocolate, fetid gas	535	545
Slate	545	650
Red slate, shelly-like (pink rock)	650	700
Slate	700	980
Sandstone, gray	980	1005
Slate	1005	1230
Sandstone, coarse, gray and white mixed (Cherry Grove)	1230	1255
Slate	1255	1390
Sandstone, gray and pebbly (Cooper)	1390	1445
Sandstone, nearly white, pebbly, oil sand (Cooper)	1445	1459
Slate, coarse	1459	1478
Total depth		1478

Well flowed several times after being drilled in but afterwards settled down to a production of only five barrels.

Carll, on Plate 2, gives the following section, measured nearby:

Sandstone, Olean	55 feet
Concealed	170 "
Sandstone, Sub Olean	45 "
Concealed to top of well	165 "

According to Carll, this well led to the discovery of what later came to be known as the Cooper pool.

Record obtained from Report I-4, Pennsylvania Second Geol. Survey, 1883, pages 80 - 81.

NO. 25. THE "MYSTERY" OR 646 WELL. May 17, 1882. Located on northwest corner of Lot 646, Cherry Grove Township, Warren County. Elevation, 1805 feet.

	Depth in feet Top	Bot.
Conductor	0	46
Slate	46	140
Sandstone, coarse and white	140	250
Slate, cased at 225 feet	250	450
Red rock with streaks of slate	450	560
Slate	560	720
Pebble sand	720	730
Slate and gravel alternating	730	805
Shelly	805	850
Red shale (pink rock)	850	862
Slate	862	1135
Pebble sand	1135	1153
Slate	1153	1320
Sand	1320	1345
Slate	1345	1525
Shells	1525	1565
Slate	1565	1575
Sand (Cherry Grove	1575	1600
Slate (Cherry Grove)	1600	1610
Sand, oil (Cherry Grove)	1610	1630

Carll, on Plate 2, shows the top of the well to be located at the base of the Olean sandstone, which is 40 feet thick at this locality.

Record obtained from Report I-4, Pennsylvania Second Geol. Survey, 1883, pages 375 - 376.

NO. 26. CEDAR OIL COMPANY'S NO. 2 WELL. September, 1882. Located in sub-division No. 21, Lot No. 635, Cherry Grove Township, Warren County. Elevation (approximate), 1725 feet.

	Depth in feet Top	Bot.
Conductor	0	32
Sandstone, solid	32	37
Slate, soft	37	52
Sandstone, hard, fine-grained, solid	52	92
Slate and shells, cased at 218 and 320 feet	92	360
Red rock, quite red, gritty	360	385
Slate, soft	385	422
Red rock, darker, gritty	422	440
Sandstone, medium-grained, bluish	440	456
Red rock	456	474
Slate and shells	474	570
Sandstone, same as last	570	590
Slate	590	610
Red rock, brownish-red, shaly	610	670
Sandstone, coarser than last, good drilling	670	720
Slate, blue	720	752
Red rocks in layers, dark brown (pink rock)	752	792
Slate and shells	792	990
Red rock in layers, dark and variable (pink rock)	990	1080
slate and shells	1080	1160
Sandstone	1160	1190
Slate and shells	1190	1305
Sandstone, quite solid, bluish (Glade)	1305	1355
Sandstone and shale, alternating, principally sandstone	1355	1520
Slate, soft, free from shells	1522	1537
Sandstone, white, pebbly, not through oil (Cherry Grove)	1537	1548

Initial production, 1500 barrels per day.

Record obtained from Report I-4, Pennsylvania Second Geol. Survey, 1883, page 376.

NO. 27. TOLLES' WELL, NO. 1, January 12, 1878. Southwest part of Warrant No. 55, Mead Township, Warren County. Elevation, 1435 feet.

	Depth in feet Top	Bot.
Not recorded	0	25
Sandstone, gray, fine	25	35
Slaty sands	35	50
Red shales	50	60
Light shale	60	115
Blue shale	115	125
Sandstone	125	150
Blue slaty sands	150	180
Blue sands, coarse and hard	180	200
Shale or slate	200	210
Red rock	210	250
Blue shale and slate	250	350
Sandstone, black, fine	350	420
Red rock (pink rock)	420	450
Shaly sands	450	480
Red rock (pink rock)	480	500
Shales, blue, sandy	500	580
Purple shales (pink rock)	580	600
Blue shales	600	620
Dark sand	620	670
Dark shales	670	750
Dark sand	750	800
Shales	800	883
Sand (Glade)	883	908
Shale	908	993
Sand, oil (Clarendon)	993	1025

Initial production, 10 barrels per day. Improved by shooting.

Carll, on Plate 2, gives the following section, measured nearby:

Shaly sandstone	25 feet
Sandstone, Sub Olean	25 "
Concealed	272 "
Sandstone to top of well (Salamanca)	25 "

The sandstone cropping out just above the top of this well has been mapped as the Salamanca by Butts[70].

Record obtained from Report I-4, Pennsylvania Second Geol. Survey, 1883 pages 20 - 21.

NO. 28. COBHAM WELL. 1866 - 67. On southeast corner of Tract 5974, Glade Township, Warren County. Elevation, 1221 feet.

	Depth in feet	
	Top	Bot.
Conductor	0	33
Blue slate, etc.	33	300
Red rock, paint (pink rock)	300	320
Blue slate	320	560
Sandstone	560	590
Blue slate	590	710
Sandstone, micaceous, fine, ashy (Glade)	710	737
Slate and shells	737	848
Mud, gas and oil at 848 feet (Clarendon)	848	849
Shells (Clarendon)	849	865
Sandstone, bluish white, fine, gritty (Clarendon)	865	885
Shells to bottom	885	915

Carll, on Plate 1, gives the following section, measured nearby:

Sandstone, coarse (Olean)	30 feet
Conglomerate (Olean)	30 "
Concealed	55 "
Conglomerate, Sub Olean	40 "
Concealed	269 "
Sandstone	5 "
Concealed	52 "
Sandstone and flags (Salamanca)	29 "
Concealed	152 "

Tanner's Hill Red at level of top of well.

The sandstone occurring 152 feet above the level of the Tanner's Hill Red corresponds to the horizon mapped as the Salamanca by Butts[71].

Record obtained from Report I-4, Pennsylvania Second Geol. Survey, 1883, page 8.

NO. 29. L. E. MALLORY AND SON, WILKESON NO. 15 WELL. Near center of Warrant 3705, Corydon Township, McKean County. Elevation (altimeter), 2102 feet.

	Depth in feet	
	Top	Bottom
Sand, oil, Sugar Run	1426	1432
Total depth		1458

From nearby outcrops, it was found that the base of the Connoquenessing sandstone occurs 5 feet below the top of the well; the top of the Olean, 65 feet; and the base of the Olean, 104 feet.

Record obtained from L. E. Mallory and Son.

NO. 30. L. E. MALLORY AND SON, NO. 1 WELL on Warrant 3712. Located near middle of east and west line, 1200 feet north of south line of Warrant 3712, Corydon Township, McKean County.

	Depth in feet	
	Top	Bot.
Sand	815	
Sand (Sugar Run)	1047	1071
Sand, top white, bottom brown, show of oil	1314	1328
Sand and slate	1408	1474
Sand	1650	
Total depth		1708

Dry hole. Record obtained from L. E. Mallory and Son.

NO. 31. L. E. MALLORY AND SON, NO. 2 WELL on Warrant 3712. Located 1700 feet east and 500 feet south of No. 1 well, Warrant 3712, Corydon Township, McKean County.

	Depth in feet	
	Top	Bot.
Pink rock	720	
Sand, show of gas	858	
Sand, broken (Sugar Run	1170	1240
Sand, top light, bottom brown	1430	1448
Total depth		1473

Dry hole. Record obtained from L. E. Mallory and Son.

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[70] Charles Butts, Description of the Warren Quadrangle; Folio 172, U. S. Geological Survey, 1910, areal geology Map.

[71] Charles Butts, op. cit.

NO. 32. NORTH PENN GAS COMPANY'S NO. 1 WELL, May 17, 1926. Near center of Warrant 3908, Bradford Township, McKean County. (Same as No. 51, Table 3.) Elevation, 1710 feet.

	Depth in feet	
	Top	Bot.
Sand, show of gas (Sugar Run)	814	890
Sand, gas and salt water (Bradford Second)	1000	1048
Sand (Bradford Third)	1373	1423
Total depth		1423

Initial production, 207,000 cubic feet of gas per day. 155 pounds rock pressure. Record obtained from O. S. Hannum.

NO. 33. R. H. GEORGE'S WEST BRANCH NO. 58 WELL, Bradford Township, McKean County. (Same as No. 90, Table 3.) Elevation 2126 feet.

	Depth in feet	
	Top	Bot.
Sandstone, sharp	340	
Sand, white, hard (Bradford First)	1170	1195
Sand, oil and salt water (Bradford Second)	1470	1518
Total depth		1518

Record obtained from R. H. George.

NO. 34. R. H. GEORGE'S WEST BRANCH NO. 60 WELL, Bradford Township, McKean County. (Same as No. 91, Table 3.) Elevation, 2169 feet.

	Depth in feet	
	Top	Bot.
Base of Olean (from outcrop)		9
Top of Cattaraugus red beds (from outcrop)	271	
Sand, oil (Bradford Second)	1502	1553
Total depth		1553

Record obtained from R. H. George.

NO. 35. R. H. GEORGE'S WEST BRANCH NO. 41 WELL, Bradford Township, McKean County. (Same as No. 93, Table 3.) Elevation, 1584 feet.

	Depth in feet	
	Top	Bot.
Sand, show of gas 675-682 (Bradford First)	605	682
Sand	894	982
Sand, oil (Bradford Third)	1260	1298
Total depth		1349

Record obtained from R. H. George.

NO. 36. DOWNS, HANE AND COMPANY'S NO. 2 WELL. Near northwest corner of east one-half of Warrant 4335, Foster Township, McKean County. (Same as No. 24, Table 3.) Elevation (approximate), 2332 feet.

	Depth in feet	
	Top	Bot.
Sand (Olean)	18	68
Red rock	317	390
Sand and shells	390	415
Red Rock	585	600
Pink rock	830	1040
Sand (Bradford First)	1294	1318
Sand (Sugar Run)	1445	1482
Sand, brown (Chipmunk)	1565	
Sand, gas (Bradford Second)	1616	1625
Total depth		1625

Record obtained from F. G. Hane.

NO. 37. DOWNS, HANE AND COMPANY'S NO. 2 WELL. On east one-half of Lot 1, Carrolton Township, Cattaraugus County, New York. (Same as No. 9, Table 3.) Elevation (approximate), 2233 feet.

	Depth in feet	
	Top	Bot.
Red shale	230	280
Red rock	290	300
Sand, hard, show of oil (Salamanca)	356	374
Sand (Sugar Run)	1363	1381
Sand, white, salt water (Bradford Second)	1522	1528
Total depth		1528

Record obtained from F. G. Hane.

NO. 38. NICHOL RUN OIL COMPANY'S HOUGH NO. 91 WELL. Allegany Township, Cattaraugus County, New York. (Same as No. 14, Table 3.) Elevation, 2246 feet.

	Depth in feet	
	Top	Bot.
Top of Cattaraugus red beds (from outcrop)	171	
Sand, oil (Chipmunk)	1368	1387
Sand, oil (Bradford Second)	1447	1517
Sand (Bradford Third)	1788	1804
Total depth		1829

Record obtained from Nichol Run Oil Company.

NO. 39. E. F. CURTIS' KIMBALL NO. 11 WELL. Olean Township, Cattaraugus County, New York. (Same as No. 6, Table 3.) Elevation, 2340 feet.

	Depth in feet	
	Top	Bottom
Base of Olean sandstone (from outcrop)		16
Top of Cattaraugus red beds (from outcrop)	208	
Sand, oil, Bradford Third	1855	1914
Total depth		1993

Record obtained from E. F. Curtis.

NO. 40. SECTION EXPOSED IN GENESEE TOWNSHIP, Allegany County, New York. The following section was measured by Carll in the central part of Genesee Township, Allegany County, New York[72]:

	Thickness in feet
1. Olean conglomerate	
2. Gray sandstones and sandy shale, Pocono type (Knapp and Oswayo)	175
3. Greenish-gray sandstones and red and gray shale, Catskill type (Cattaraugus)	225
4. Massive flat-pebble conglomerate, Catskill type. (Cattaraugus)	25
5. A repetition of No. 3. Catskill type (Cattaraugus)	125
6. Shales and flaggy sandstones. Chemung type	250

NO. 41. WELL NO. 91 OF THE UNITED NATURAL GAS COMPANY of Clarksville, Allegany County, New York. Located on the Hatch farm, Lot No. 2 in the southeastern part of Clarksville Township, Allegany County, New York. Elevation (aneroid), 2300 feet.

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
58	Light-green to green shale with a little interbedded brownish-red shale and red sandy shale	0	58
19	Dark-red sandy shale	58	77
19	Moderately coarse-grained greenish-gray micaceous sandstone	77	96
39	Coarse-grained light-gray quartz sandstone	96	135
19	Fine-grained greenish-gray sandstone	135	154
20	Blue and olive shale	154	174
19	Fine-grained grayish-buff micaceous sandstone	174	193
19	Bluish-gray shale and sandy shale	193	212
20	Interbedded blue and red shale with some greenish-gray sandstone	212	232
	Bottom of Cattaraugus red beds		232
19	Blue shale with some interbedded light-gray sandstone	232	251
58	Blue shale, slightly sandy	251	309
19	Blue to green shale	309	328
20	Blue shale	328	348
58	Blue shale with a little interbedded gray sandy shale	348	406
19	Interbedded brownish-red sandy shale, gray sandy shale, and blue shale	406	425
39	Bluish-gray shale	425	464
19	Gray sandy shale with a little interbedded brownish-red sandy shale	464	483
19	Olive to gray shale with a little interbedded brownish-red shale	483	502
20	Olive to gray shale	502	522
19	Fine-grained light-gray micaceous sandstone	522	541
39	Greenish-gray shale	541	580
38	Blue shale with some interbedded fine-grained, light-gray sandstone	580	618
20	Olive shale	618	638
19	Fine-grained, light-gray sandstone	638	657
19	Blue shale	657	676
116	Interbedded fine-grained light-gray sandstone and blue shale	676	792
20	Blue sandy shale	792	812
18	Light-gray sandstone (Bradford First)	812	830
16	Olive shale with some interbedded red oölitic iron ore	830	846
33	Olive to blue shale	846	879

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[72] John F. Carll. Report on the oil and gas regions, annual report, Second Pennsylvania Geol. Survey for 1886, Part II, 1887, p. 639.

Thickness feet	Description of strata	Depth in feet Top	Bottom
33	Olive to blue shale with a little interbedded brownish-red shale	879	912
33	Bluish-gray and light-gray sandy shale, in part calcareous	912	945
17	Olive shale, in part micaceous and sandy with a little interbedded purple shale	945	962
16	Olive to greenish-gray shale, slightly micaceous and sandy	962	978
17	Olive to bluish-gray shale with a little interbedded purple shale	978	995
16	Bluish-gray and light-gray calcareous sandy shale	995	1011
49	Fine-grained greenish-gray sandstone, somewhat calcareous in lower part	1011	1060
60	Interbedded fine-grained gray sandstone and blue shale	1060	1120
15	Greenish-gray shale, fossiliferous	1120	1135
15	Olive shale, slightly sandy	1135	1150
15	Dark to slightly brownish-gray shale	1150	1165
30	Olive shale, slightly sandy in lower half	1165	1195
15	Dark gray shale with some interbedded fine-grained light-gray sandstone	1195	1210
45	Greenish-gray shale	1210	1255
30	Fine-grained light-gray to gray sandstone and interbedded greenish-gray shale	1255	1285
60	Fine-grained brownish-gray sandstone, fossiliferous, with a little interbedded shale	1285	1345
12	Interbedded sandstone and sandy shale	1345	1357
25	Brownish-gray sandstone with a little interbedded shale, fossiliferous, gas (Richburg Stray)	1357	1382
11	Interbedded brownish-gray sandstone and greenish-gray shale, fossiliferous	1382	1393
11	Greenish-gray shale	1393	1404
11	Greenish-gray shale with a little interbedded brownish gray sandstone	1404	1415
26	Fine-grained brownish-gray micaceous sandstone with a little interbedded greenish-gray shale (Richburg)	1415	1441

The above detailed record has been compiled from Prosser's description of a set of samples of the drill cuttings[73].

NO. 42. BELMONT QUADRANGLE DRILLING CORPORATION'S GILBERT NO. 1 WELL. Located 2 miles north of Richburg, Wirt Township, Allegany County, New York.

A description of the strata penetrated by this well is given under No. 12 of the deep well records.

NO. 43. ELKO OIL AND GAS COMPANY'S HOTCHKISS NO. 2 WELL. Located 1½ miles south of Randolph, Randolph Township, Cattaraugus County, New York.

A description of the strata penetrated by this well is given under No. 1 of the deep well records.

NO. 44. E. A. WILLIAMS' LAUGHLIN NO. 1 WELL. 1921. Located on O. Laughlin farm near Corydon, Corydon Township, Warren County. Elevation (approximate), 1280 feet.

	Depth in feet Top	Bot.
Sand (Clarendon)	489	501
Sand, some salt water (Gartland)	625	
Sand	704	720
Sand	1005	1010
Sand, gray, 75,000 cubic feet gas in top	1360	1396
Sand, brown and gray	2015	2036
Sand, gray, show of oil	2310	2390
Total depth		2520

Record obtained from E. A. Williams.

NO. 45. TOMES WELL. 1896. Along Willow Creek in western part of Warrant 3717, Corydon Township, Warren County. Elevation (approximate), 1440 feet.

	Depth in feet Top	Bot.
Sand	425	440
Sand, gas at top (Sugar Run)	623	723
Sand	920	960
Sand	1120	1160
Sand	1280	1320
Sand	1325	1328
Total depth		1440

Record obtained from E. A. Williams.

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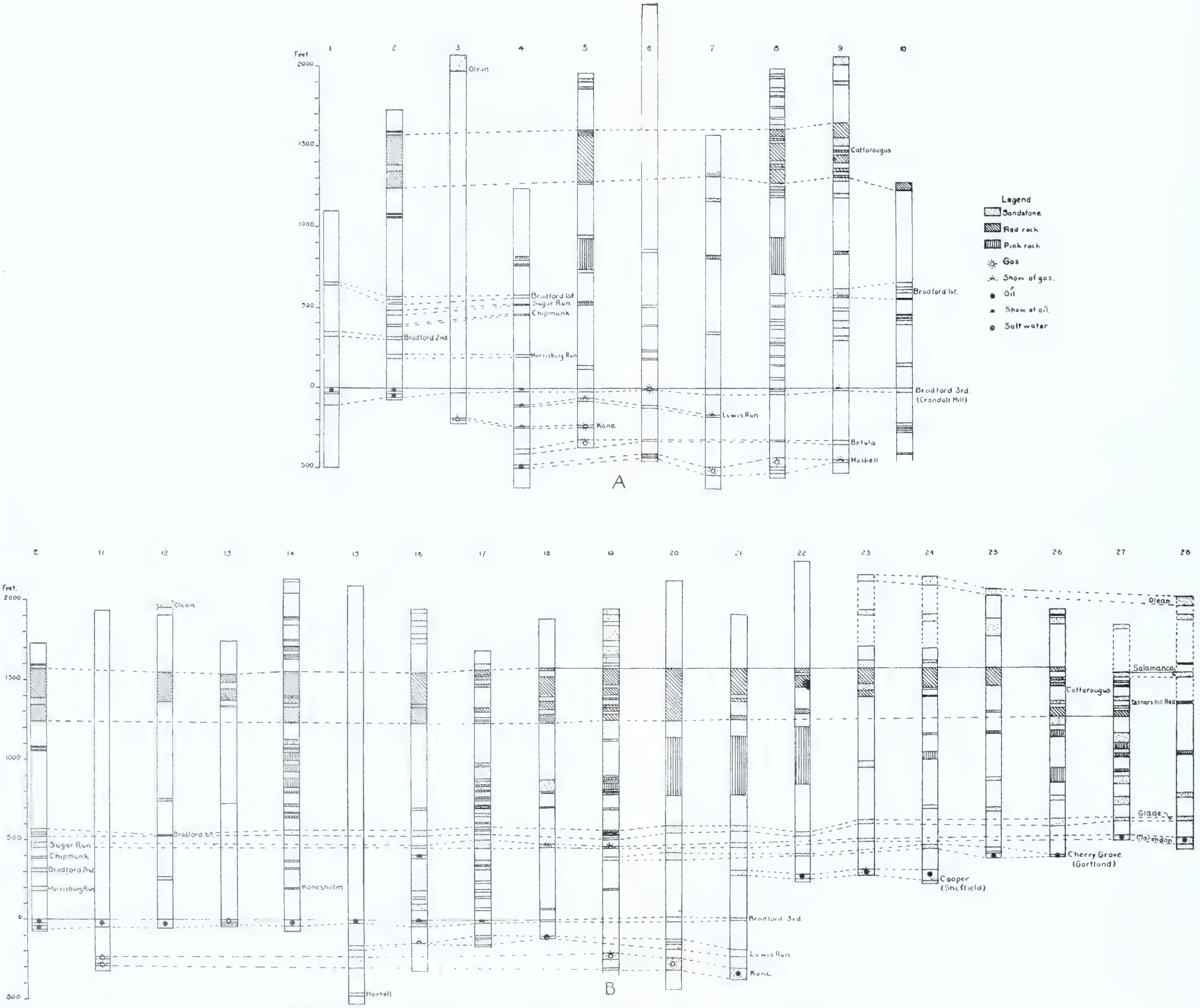
[73] Charles S. Prosser, The thickness of the Devonian and Silurian rocks of Western New York; approximately along the line of the Genesee River. Proc. Rochester Acad. of Sci., vol. 2, 1892, pages 56-65.

PLATE 9



Selected well sections in southern McKean County and adjacent areas.

NO. 46. E. A. WILLIAMS' HOLSINGER NO. 1 WELL. August, 1917. Along Willow Creek in western part of Warrant 4873, Corydon Township, McKean County. Elevation (altimeter), 1707 feet

	Depth in feet Top	Bot.
Sand, white, show of gas Bradford First)	789	
Sand, white and brown, oil (Sugar Run)	869	901
Sand	1620	1627
Total depth		1650

Initial production, 3 barrels per day. Record obtained from E. A. Williams.

NO. 47. E. A. WILLIAMS' WELL in northeast corner Warrant 4873, Corydon Township, McKean County.

	Depth in feet Top	Bot.
Sand (Salamanca)	150	230
Shell, show of gas	500	
Sand, white and pebbly, show of oil (Sugar Run)	1103	1151
Sand, chocolate colored, show of oil (Bradford Second)	1309	1344
Total depth		1527

Record obtained from E. A. Williams.

NO. 48. E. A. WILLIAMS' WELL on Warrant 4917. Located 1200 feet west of southeast corner of Warrant 4917, Foster Township, McKean County.

	Depth in feet Top	Bot.
Sand (Bradford First)	940	980
Sand (Sugar Run)	1060	1160
Sand, show of oil and much salt water (Bradford Second)	1305	1350
Total depth		1350

Record obtained from E. A. Williams.

Under A, Plate 9, a series of well sections, selected from the group just described, has been arranged to show graphically the relation of the Bradford Third and other sands of the Bradford district to the productive horizons of southeastern McKean and western Potter Counties. The numbers assigned to the sections correspond to the locations shown on Figure 4. The sections have been lined up on the top of the Bradford Third sand, the correlations of this horizon outside the Bradford district in the southeastern part of McKean and the western part of Potter County being based largely on its position with respect to the Cattaraugus formation.

It will be observed that the Crandall Hill sand, the main shallow producing horizon in the Coudersport gas pool in western Potter County, occupies the stratigraphic position of the Bradford Third sand, a fact commonly recognized by the drillers. On the other hand, the sand frequently referred to as the Kane in the Betula and Colegrove gas pools of southeastern McKean County apparently lies at a somewhat lower horizon than the sand known as the Kane in the Bradford district. The name Betula is, therefore, proposed for it from the fact that it is a source of gas in parts of that pool. The deepest producing sand in southeastern McKean County, sometimes called the Elk, corresponds in stratigraphic position to the Haskell sand of the Bradford district.

Under B, Plate 9, another series of well sections has been arranged to show the relation of the sands recognized in the Bradford district to those of the southwestern part of McKean and adjacent portions of Elk, Forest, and Warren Counties. No. 2 and Nos. 11 to 18, inclusive, have been lined up on the top of the Bradford Third sand; Nos. 18 to 26, inclusive, on the top of the Cattaraugus red beds; 26 and 27, on the bottom of the red beds; and 27 and 28, on the top of the Salamanca sandstone. In the case of Nos. 13 to 18, inclusive, which are located outside the Bradford district, correlation of the Bradford Third sand horizon has been based upon its position with respect to sea-level, taking the structure into consideration. The top of the Cattaraugus red beds was selected for lining up wells 18 to 26, inclusive, because it has been found that drillers are more apt to observe correctly and record the depth at which the red rock first appears than they are to record the bottom. Nos. 27 and 28 are in the Warren district where, as has already been stated, the red beds largely disappear from the upper part of the Cattaraugus formation so that it becomes impossible to distinguish this formation from the overlying Oswayo. Nos. 26 and 27 have, therefore, been lined up on the base of the red beds and Nos. 27 and 28 on the top of the Salamanca sandstone.

Well No. 2, located in the north central part of the Bradford pool, shows the position of the various sands commonly recognized above the Bradford Third in the Bradford district. No. 11 shows the position of the sand known as the Kane in the Bradford district with respect to the Bradford Third. Nos. 19, 20 and 21 are in the Kane field of southwestern McKean and adjacent parts of Elk County, the type locality for the Kane sand. No. 23 is in the Sheffield field, the type locality for the Sheffield sand; and No. 24, on the edge of the Cooper pool, the type locality for the Cooper sand. Nos. 25 and 26 are in the Cherry Grove pool of southeastern Warren County, the type locality for the Cherry Grove sand, and Nos. 27 and 28 in the Clarendon pool southeast of Warren. Three oil sands, the Glade, Clarendon and Gartland, in descending order, are commonly recognized in the Warren district, of which the Clarendon pool is a part. The Clarendon lies from 50 to 140 feet below the top of the Glade and the Gartland 40 to 50 feet below the top of the Clarendon[74].

Wells Nos. 27 and 28 did not reach the horizon of the Gartland sand, which corresponds approximately in stratigraphic position to the Cherry Grove.

An examination of the sections lined up under B, Plate 9, shows that the Bradford First sand of the Bradford district occupies approximately the same stratigraphic horizon as the Glade sand of the Warren district; the Sugar Run, as the Clarendon; the Chipmunk, as the Gartland and Cherry Grove; and the Bradford Second, as the Cooper and Sheffield; and the Harrisburg Run as the Kanesholm. It also brings out the fact that the sand called the Kane in the Bradford district has been correctly correlated with the Kane of the Kane field.

Under A, Plate 10, is shown a series of well logs extending from the Clarendon pool in Warren County through the Sugar Run and Bradford pools of McKean County, Pennsylvania and Cattaraugus County, New York, to the Richburg pool in Allegany County, New York. Nos. 28 to 32, inclusive, are lined up on the top of the Clarendon and Sugar Run sand; Nos. 32 to 37, 1, and 38, on the top of the Bradford Second; and Nos. 38, 2, 39 to 42, and 10, on the top of the Bradford Third.

The relative stratigraphic positions of the Sugar Run and Bradford Second sands were determined from their positions with respect to the base of the Olean conglomerate as determined in wells Nos. 29 and 34. No. 29, in the Sugar Run pool, is 8.4 miles southwest of No. 34 at the western margin of the Bradford pool. In No. 29 the interval between the base of

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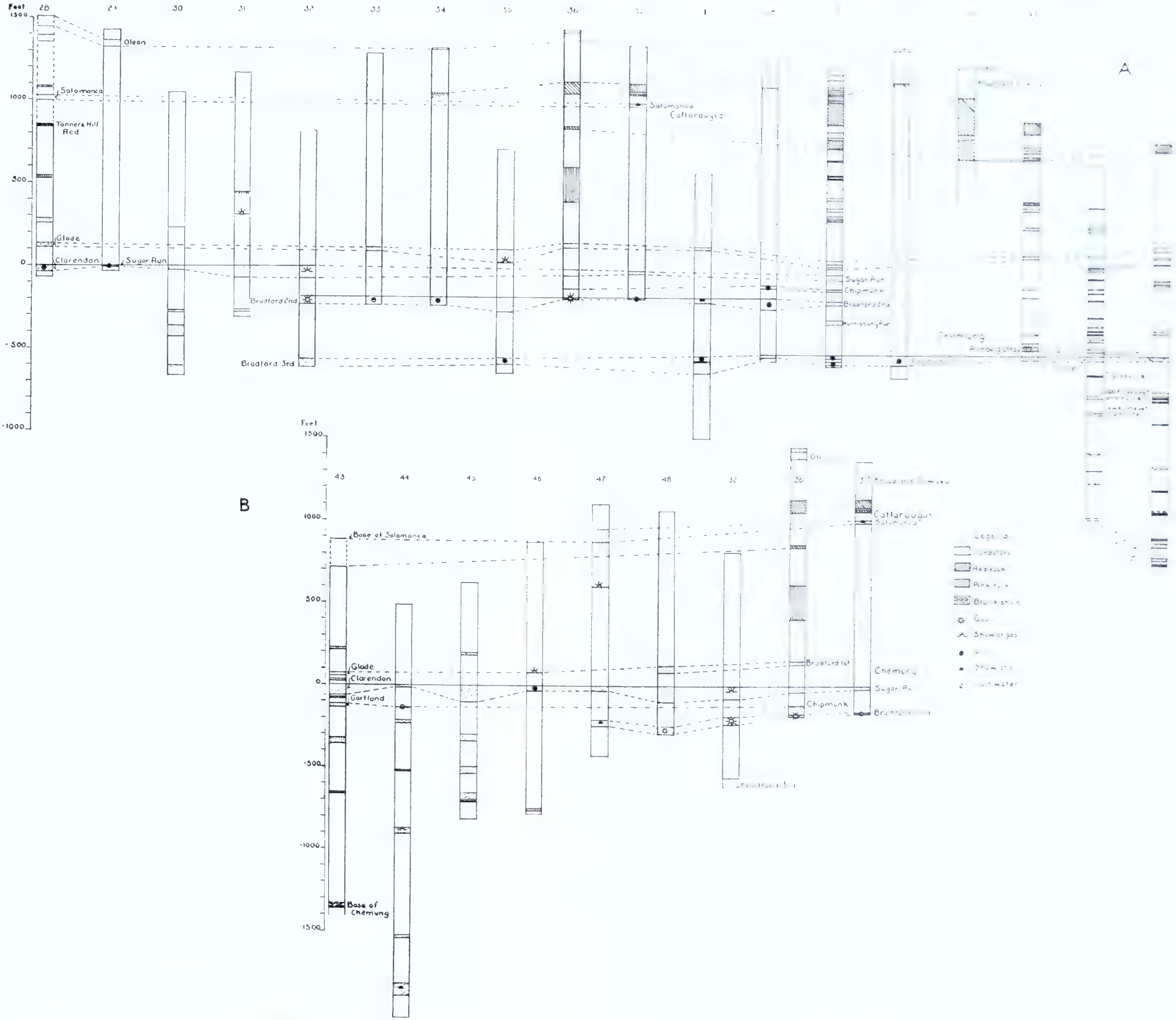
[74] Charles Butts, Description of the Warren Quadrangle: Folio No. 172, U. S. Geol. Survey, 1910, p. 10.



Selected well sections in northern McKean County and adjacent areas.

the Olean and the top of the Sugar Run sand is 1322 feet, whereas in No. 34 the interval between the base of the Olean and the top of the Bradford Second sand is 1493 feet, a difference of 171 feet. It is realized that the base of the Olean is a poor horizon to use for correlating the underlying sands on account of the intervening unconformity. It was the best that was available, however, inasmuch as no records of wells in the Sugar Run pool, the type locality for the Sugar Run sand, were obtained that showed the position of the Cattaraugus red beds with respect to this sand, nor were any good exposures of these beds found in the vicinity showing either their upper or lower limits. A number of well records obtained in the area to the east, occupied by the Bradford pool, indicate that there is a sand between the Bradford First and the Chipmunk which occupies the stratigraphic position assigned to the Sugar Run. A sand was also recognized at this horizon in the complete set of drill cuttings examined from No. 2 well.

The correlation of the Sugar Run sand, as identified in the Bradford district, with the Clarendon sand of the Warren district is based upon their stratigraphic positions with respect to the Salamanca horizon and the base of the Cattaraugus formation. In well No. 2, the Sugar Run sand lies 762 feet below the base of the Cattaraugus formation, whereas in No. 28 the Clarendon sand lies 848 feet below the Tanners Hill red. According to Butts[75], the latter lies about 100 feet above the bottom of the Cattaraugus formation. Caster, on the other hand, believes that the Tanners Hill red lies immediately below the base of the Cattaraugus[76]. Well No. 28 is 15 miles slightly south of west of No. 29. At 28 a series of dark-bluish sandy shales and fine-grained argillaceous sandstones with occasional thin sandstone and conglomerate layers, similar to those described in the Guffey section in the extreme southern part of the Bradford district, appears above the Knapp formation as developed in the vicinity of Bradford and below the Olean, so that the interval between the base of the Olean and the top of the Clarendon sand is correspondingly increased[77].

The sections lined up under A, Plate 10, also indicate that the Bradford First sand of the Bradford district occupies approximately the same stratigraphic position as the Glade sand of the Warren district and that on the basis of their relative position with respect to the bottom of the Cattaraugus red beds, the Richburg sand of the Richburg pool in Allegany County, New York and the Crandall Hill sand of the Coudersport gas pool in western Potter County, Pennsylvania, lie at about the geologic horizon of the Bradford Third sand and that this horizon occurs at approximately the middle of the Chemung (Chautauquan) group.

Under B, Plate 10, are shown graphically a series of well records covering the northwestern part of McKean County and the upper portion of a deep well south of Randolph in the southwestern part of Cattaraugus County, New York. The logs are lined up on the top of the Sugar Run sand. Correlation has been based upon position with respect to the Salamanca horizon and bottom of the Cattaraugus formation, as well as elevation above sea-level, taking structure into consideration.

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[75] Charles Butts, op. cit., p. 4.

[76] Kenneth E. Caster, The stratigraphy and paleontology of northwestern Pennsylvania, Part I; Stratigraphy. Bull. Amer. Paleontology, vol. 21, no. 71, 1934, pp. 67, 79 and 82.

[77] Charles Butts, op. cit., p. 5.

Inspection of the four series of well records shown on Plates 9 and 10, shows that the upper Devonian oil and gas sands of McKean County and adjacent areas occur in the middle portion of the Chemung (Chautauquan) group. They all represent lenticular rather than continuous bodies of sandstone, the Bradford Third perhaps being the most persistent in the area under discussion. Since only a hundred feet or so of strata intervene between the individual horizons, exact correlation from one pool to another is difficult, particularly as there are no good horizon markers in the group itself. In most instances, one is only justified in stating that a sand in one pool occurs at approximately the same stratigraphic horizon as a sand in another pool, although the distance separating the two may be relatively small.

Summarizing, it has been shown that the Glade sand of the Warren district corresponds closely in stratigraphic position to the Bradford First; the Clarendon, to the Sugar Run; the Gartland and Cherry Grove, to the Chipmunk; and the Cooper and Sheffield of southeastern Warren and northeastern Forest Counties, to the Bradford Second. The Richburg sand of Allegany County, New York and the Crandall Hill sand of western Potter County occcur at about the same horizon as the Bradford Third. The Kane sand of the Bradford district has been correctly correlated by the drillers with the Kane of the Kane field, but the sand called the Kane in southeastern McKean County occurs at a somewhat lower horizon. The name Betula has, therefore, been proposed for it. The Elk sand of southeastern McKean County corresponds in stratigraphic position to the Haskell sand of the Bradford district.

DEEP WELLS

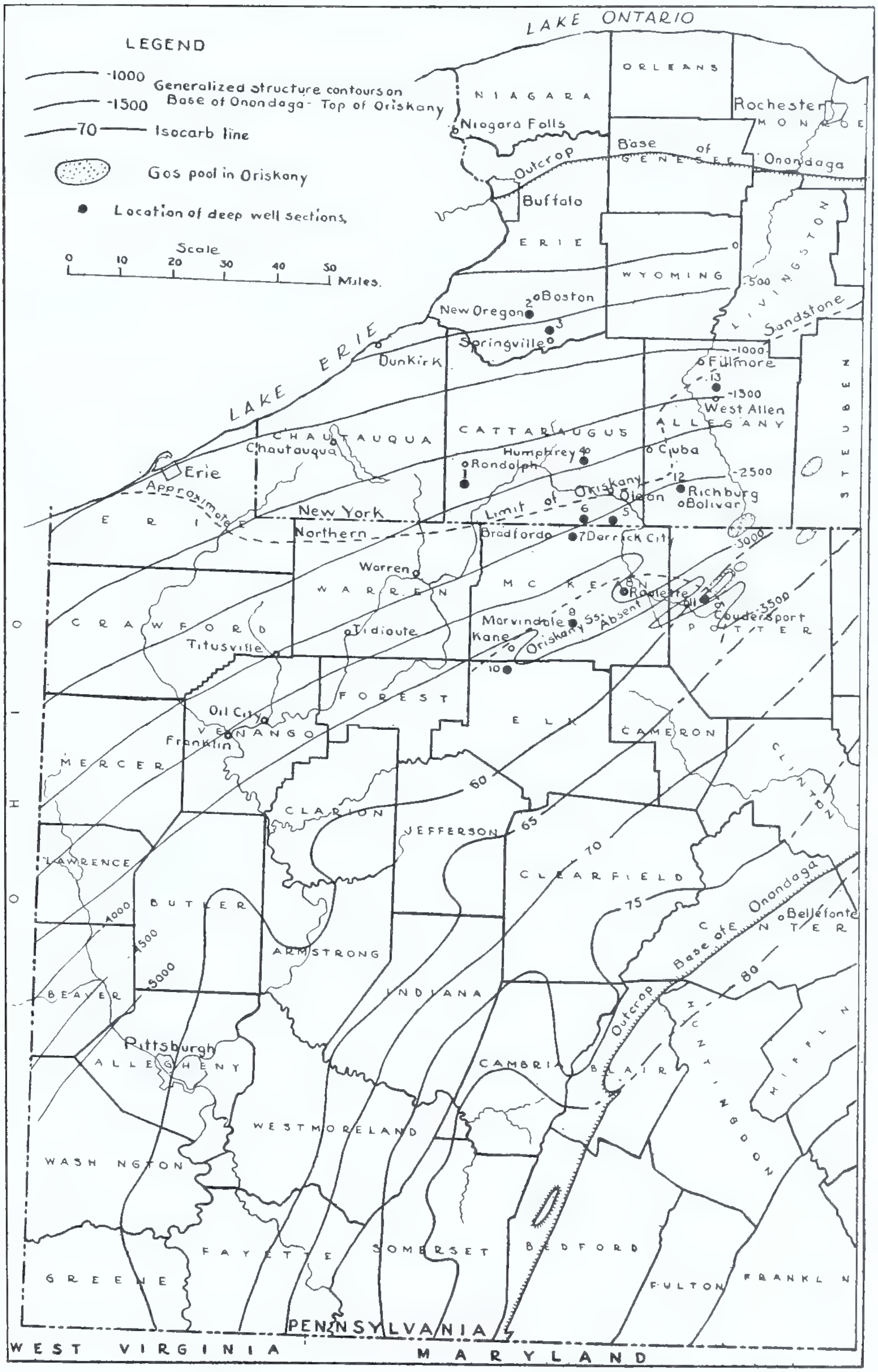
Three wells to date, January 1935, completed in the Bradford district, have penetrated strata older than the Upper Devonian. One of these reached the Queenston red shale at the top of the Ordovician system and the other two, the Oriskany sandstone of the Lower Devonian. Deep tests have also been drilled in the adjacent territory on practically all sides so that considerable information is available on the subsurface stratigraphy of the district to the top of the Ordovician system, the deepest horizon thus far reached by the drill in this area.

The sections obtained from thirteen deep wells have been selected to show the subsurface stratigraphy of the area of which the Bradford district forms a part. The locations of these wells, numbered from 1 to 13, are shown on Plate 11. No. 10 is 68 miles south of No. 2 and No. 11, 51 miles southeast of No. 1.

The sections furnished by the thirteen wells are shown graphically on Plate 12 in as much detail as the scale permits. They have been lined up on the base of the Onondaga limestone, a horizon which is readily recognizable throughout the area under discussion. A detailed description of each section follows:

Section No. 1

During 1924 to 1930, the Elko Oil and Gas Company and its successor, the Arkansas Fuel Oil Company, drilled three deep wells 1½ miles south of Randolph in the town of Randolph, Cattaraugus County, New York on the Hotchkiss and Crandall farms. Hotchkiss No. 1, which started at an elevation of 1764 feet above sea-level, had penetrated 89 feet of red Medina when the



Map showing location of 13 deep well sections and generalized structure contours on the base of the Onondaga limestone.

well was abandoned at a depth of 4684 feet on account of a lost string of tools. An open flow of 300,000 cubic feet of gas per day was reported in the last ten feet drilled. Crandall No. 1, which started at an elevation of 1770 feet, was abandoned in the Lockport dolomite at a depth of 4458 feet when the casing collapsed. Hotchkiss No. 2, starting at an elevation of 1760 feet, was abandoned at a depth of 4484 feet on account of drilling difficulties after reaching the base of the Lockport.

A complete set of samples of the cuttings from Hotchkiss No. 2 from a depth of 478 feet to the bottom of the hole was taken. The following detailed record is based upon the study made of these samples. According to Tester[78] the well started at about the base of the Cattaraugus formation and 170 feet below the horizon of the Salamanca conglomerate.

Record of Hotchkiss No. 2 Well

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
	Top of Chemung group (approximate) Chadakoin beds		
478	No samples collected	0	478
16	Greenish-gray sandy shale with some interbedded dark reddish-brown sandy shale	478	494
8	Fine to medium-grained, greenish-gray sandstone, somewhat calcareous	494	502
40	Greenish-gray sandy shale with some interbedded dark reddish-brown sandy shale	502	542
8	Greenish-gray sandy shale	542	550
8	Fine-grained, light greenish-gray sandstone	550	558
56	Greenish-gray sandy shale	558	614
32	Dark greenish-gray shale	614	646
16	Fine-grained light greenish-gray sandstone, sparingly fossiliferous (Glade sand)	646	662
	Bottom of Girard beds		662
24	Dark gray shale	662	686
8	Very fine-grained, light greenish-gray sandstone, fossiliferous	686	694
16	Dark gray shale	694	710
8	Dark gray sandy shale	710	718
64	Fine-grained, light-gray sandstone (Clarendon sand)	718	782
8	Gray shale	782	790
8	Fine-grained, light-gray sandstone	790	798
32	Light greenish-gray sandy shale	798	830
24	Very fine-grained light greenish-gray sandstone (Gartland sand)	830	854
186	Gray shale, sparingly fossiliferous	854	1040
35	Very fine-grained, light greenish-gray sandstone (Shumla sandstone—Bradford Second?)	1040	1075
	Bottom of Northeast beds		1075
91	Gray shale, fossilferous	1075	1166
56	Dark-gray shale	1166	1222
84	Gray shale, fossiliferous	1222	1306
28	Dark-gray shale	1306	1334
24	Gray sandy shale	1334	1358
14	Gray shale	1358	1372
7	Very fine-grained, greenish-gray argillaceous sandstone, calcareous (Laona sandstone)	1372	1379
	Bottom of Westfield beds		1379
98	Gray to dark-gray shale with some interbedded thin layers of very fine-grained, light-gray somewhat calcareous sandstone	1379	1477
21	Gray sandy shale	1477	1498
21	Gray shale with some interbedded thin layers of very fine-grained, light-gray, somewhat calcareous sandstone	1498	1519
7	Gray sandy shale	1519	1526
49	Gray shale	1526	1575
7	Greenish-gray sandy shale	1575	1582
28	Gray shale	1582	1610
21	Greenish-gray sandy shale	1610	1631

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[78] A. C. Tester, written communication, June 20, 1931.

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
260	Interbedded gray shale and greenish-gray sandy shale	1631	1891
	Bottom of Gowanda beds		1891
49	Very dark gray, almost black, shale with some interbedded light greenish-gray sandy shale	1891	1940
78	Gray shale with some interbedded light-gray sandy shale and very fine-grained sandstone	1940	2018
21	Greenish-gray sandy shale	2018	2039
14	Gray shale with some interbedded grayish-black shale	2039	2053
7	Grayish-black shale	2053	2060
7	Gray shale, in part calcareous	2060	2067
10	Grayish-black shale	2067	2077
	Bottom of Dunkirk black shale		2077
	Top of Portage group	2077	
50	Greenish-gray sandy shale with some interbedded gray shale	2077	2127
10	Very fine-grained greenish-gray sandstone	2127	2137
50	Greenish-gray sandy shale with some interbedded gray shale	2137	2187
80	Gray shale with some interbedded greenish-gray sandy shale	2187	2267
	Bottom of Wiscoy beds		2267
30	Greenish-gray sandy shale	2267	2297
20	Gray shale	2297	2317
10	Very fine-grained greenish-gray sandstone, somewhat calcareous	2317	2327
57	Greenish-gray sandy shale with some interbedded black shale	2327	2384
	Bottom of Nunda beds		2384
14	Gray shale	2384	2398
19	Grayish-black shale	2398	2417
37	Gray shale with some interbedded gray sandy shale	2417	2454
14	Gray shale with some interbedded black shale	2454	2468
7	Black shale	2468	2475
28	Gray shale with a little interbedded black shale	2475	2503
	Bottom of Gardeau beds		2503
7	Greenish-gray sandy shale (Grimes)	2503	2510
70	Gray shale with some interbedded black shale	2510	2580
7	Black shale	2580	2587
21	Gray shale with some interbedded black shale	2587	2608
19	Black shale	2608	2627
28	Very dark gray shale	2627	2655
28	Very dark gray shale with some interbedded black shale	2655	2683
	Bottom of Hatch beds		2683
7	Black shale	2683	2690
7	Very dark gray shale	2690	2697
31	Black shale	2697	2728
	Bottom of Rhinestreet black shale		2728
140	Dark-gray shale, slightly calcareous and sparingly fossiliferous, with some interbedded black shale (Cashaqua)	2728	2868
43	Grayish-black shale (Middlesex)	2868	2911
42	Dark-gray shale with some interbedded thin layers of greenish-brown limestone (West River)	2911	2953
7	Very fine, crystalline, grayish-brown limestone (Genundewa)	2953	2960
	Top of Hamilton group	2960	
42	Dark-gray shale with some interbedded thin layers of grayish-brown limestone	2960	3002
7	Very fine, crystalline, dark grayish-brown limestone (Tichenor)	3002	3009
42	Dark-gray shale, slightly calcareous, with some interbedded thin layers of grayish-brown limestone	3009	3051
49	Very dark gray shale, slightly calcareous	3051	3100
98	Brownish-black shale, slightly calcareous	3100	3198
14	Very dark gray shale, slightly calcareous	3198	3212
7	Brownish-black shale, somewhat calcareous	3212	3219
21	Very dark gray shale, slightly calcareous	3219	3240
7	Grayish-black shale, slightly calcareous	3240	3247
7	Very dark gray shale, slightly calcareous	3247	3254
77	Black shale, slightly calcareous	3254	3331
21	Very dark brownish-gray shale, somewhat calcareous	3331	3352
7	Very fine, crystalline, dark brownish-gray limestone	3352	3359

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
7	Very dark brownish-gray shale, somewhat calcareous	3359	3366
14	Black shale	3366	3380
	Bottom of Hamilton group		3380
154	Very fine, crystalline, grayish-brown cherty limestone (Onondaga)	3380	3534
9	Very fine, dark grayish-brown siliceous magnesian limestone (Cobleskill)	3534	3543
	Top of Salina group	3543	
45	Very fine, dark grayish-brown argillaceous magnesian limestone (Bertie)	3543	3588
99	Very fine, dense, very dark brownish-gray argilaceous magnesian limestone containing some anhydrite	3588	3687
46	Very fine, dense, dark grayish-brown, argillaceous magnesian limestone containing some anhydrite	3687	3733
90	Very fine, dense, brownish-gray to dark brownish gray argillaceous and siliceous limestone containing a little anhydrite	3733	3823
40	Very fine, dense, light brownish-gray argillaceous magnesian limestone containing a little anhydrite	3823	3863
10	Very fine, dense, grayish-brown argillaceous limestone	3863	3873
20	Interbedded light bluish-gray shale and very fine, dense, grayish-brown argillaceous limestone. A few medium-sized, well-rounded quartz grains occur at this horizon	3873	3893
30	Interbedded bluish-gray shale and very fine, dense, brownish-gray argillaceous limestone containing a little salt and anhydrite	3893	3923
50	Greenish-gray shale with a very little interbedded red shale. Contains a little anhydrite	3923	3973
20	Greenish-gray shale with considerable interbedded anhydrite	3973	3993
37	Greenish and bluish-gray shale, somewhat calcareous	3993	4030
40	Gray to dark shale, somewhat calcareous	4030	4070
50	Very fine, dense, dark grayish-brown, very argillaceous limestone	4070	4120
20	Very fine, dense, dark grayish-brown argillaceous limestone containing a little salt	4120	4140
10	Very fine, dense, brownish-gray argillaceous limestone with some interbedded bluish-gray shale	4140	4150
30	Very fine, dense, brownish-gray argillaceous limestone	4150	4180
30	Interbedded dark greenish-gray shale and very fine, dense, brownish-gray argillaceous limestone	4180	4210
	Top of Lockport dolomite	4210	
90	Very fine, dense, dark brownish-gray argillaceous, dolomitic limestone	4210	4300
184	Very fine, crystalline, dark grayish-brown dolomitic limestone	4300	4484
	Total depth		4484

Samples of the cuttings obtained from the lower part of the Hotchkiss No. 1 well showed that the bottom of the Lockport dolomite was encountered at a depth of 4455 feet and the top of the Medina group at 4595 feet. This gives a thickness of 140 feet for the Clinton group, including the Rochester shale, at the Randolph locality. The Medina was penetrated to a depth of 89 feet in No. 1 well.

Three prominent sandstone members encountered in the upper part of the Chemung in the Hotchkiss well have been correlated with the Glade, Clarendon, and Gartland oil sands, respectively, of the Warren, Pennsylvania, district with which they correspond in stratigraphic position. The base of a black shale occurring at a depth of 2077 feet has been correlated with the bottom of the Dunkirk shale[79] of the Lake Erie section. Inasmuch as the well is 30 miles southeast of Dunkirk, New York, where the base of the shale crops out at lake level, the bed has an average dip of 30 feet per mile to the southeast between Dunkirk and Randolph. The base of the Portage group has been identified by the presence of a thin bed of limestone which, it is believed, represents the Genundewa horizon. The Genesee black shale apparently is absent, as would be expected, since at Eighteen Mile Creek, along Lake Erie, it is less than an inch thick[80].

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[79] D. Dana Luther, Stratigraphy of Portage formation between the Genesee Valley and Lake Erie; New York State Mus. Bull. 69, 1903, pp. 1025-1026. George H. Chadwick, The stratigraphy of the Chemung group in Western New York, New York State Mus. Bull. 251, 1924, p. 149.

Section No. 2

Section No. 2 was obtained in Well No. 796 of the Iroquois Gas Corporation, two miles east of New Oregon in the town of Concord, Erie County, New York, at an elevation of 1560 feet above sea-level. The well was drilled during the latter part of 1925. No commercial production of oil or gas was encountered. The following record is based on the examination of a complete set of samples of the cuttings:

Record of Iroquois Gas Corporation's No. 796 Well

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
42	No samples collected	0	42
74	Very fine grained, light-gray, somewhat micaceous sandstone with a little interbedded very dark gray shale (Laona)	42	116
37	Gray sandy shale with a little interbedded very fine grained gray sandstone	116	153
7	Very fine grained gray, slightly calcareous sandstone with some interbedded gray sandy shale	153	160
15	Gray sandy shale	160	175
6	Very fine grained, light-gray, slightly calcareous sandstone with some interbedded gray shale	175	181
33	Gray shale with a little interbedded very fine grained gray sandstone and dark-gray sandy shale	181	214
6	Dark-gray sandy shale	214	220
36	Gray shale with some interbedded very fine grained gray calcareous sandstone	220	256
66	Gray shale	256	322
19	Gray sandy shale	322	341
25	Gray shale with some interbedded very fine grained gray calcareous sandstone	341	366
6	Very fine grained gray calcareous sandstone with some interbedded very dark gray shale	366	372
43	Gray shale with some interbedded very dark gray sandy shale and a little very fine grained gray calcareous sandstone	372	415
7	Gray sandy shale with some interbedded very fine grained gray calcareous sandstone	415	422
15	Gray shale with some interbedded gray sandy shale and a little very fine grained gray calcareous sandstone	422	437
54	Very dark gray sandy shale with a little interbedded very fine grained gray sandstone and gray shale	437	491
6	Very fine grained light-gray to gray calcareous sandstone with some interbedded very dark gray sandy shale	491	497
20	Interbedded gray shale and very dark gray sandy shale	497	517
7	Very fine grained gray calcareous sandstone with some interbedded very dark gray sandy shale	517	524
6	Gray shale	524	530
7	Very dark gray sandy shale with some interbedded very fine grained somewhat calcareous sandstone (show of gas at 531 feet)	530	537
25	Gray shale with some interbedded very dark gray sandy shale (show of gas at 540 feet)	537	562

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[80] A. W. Grabau, Stratigraphic relationship of the Tully limestone and the Genesee shale in eastern North America: Bull. Geol. Soc. America, vol. 28, 1917. p. 949.

Thickness feet	Description of strata	Depth in feet Top	Bottom
12	Very fine grained gray, somewhat calcareous sandstone with some interbedded gray shale	562	574
6	Very dark gray sandy shale	574	580
6	Very fine grained gray, somewhat calcareous sandstone with some interbedded very dark gray sandy shale	580	586
14	Interbedded gray shale and sandy shale	586	600
7	Very fine grained gray, somewhat calcareous sandstone with some interbedded very dark gray sandy shale	600	607
	Top of Dunkirk black shale	607	
123	Grayish-black sandy shale (show of gas at 670 feet)	607	730
7	Gray shale	730	737
46	Very fine grained light-gray to greenish-gray sandstone with some interbedded grayish-black sandy shale	737	783
	Top of Portage group	783	
14	Greenish-gray sandy shale with some interbedded grayish-black sandy shale	783	797
13	Gray sandy shale	797	810
6	Very fine grained gray sandstone with some interbedded gray sandy shale	810	816
19	Grayish-black sandy shale with some interbedded gray sandy shale	816	835
11	Black shale	835	846
	Bottom of Wiscoy beds		846
9	Gray sandy shale	846	855
11	Very fine grained gray, somewhat calcareous sandstone with some interbedded gray sandy shale	855	866
21	Gray sandy shale with some interbedded very fine grained gray sandstone	866	887
6	Very fine grained, somewhat calcareous sandstone with some interbedded gray sandy shale	887	893
34	Gray sandy shale with a little interbedded very fine grained gray, somewhat calcareous sandstone	893	927
7	Very fine grained greenish-gray, somewhat calcareous sandstone	927	934
	Bottom of Nunda beds		934
100	Interbedded gray sandy shale and shale	934	1034
	Bottom of Gardeau beds		1034
7	Very fine grained gray, somewhat calcareous sandstone (Grimes)	1034	1041
70	Interbedded gray sandy shale and shale	1041	1111
21	Grayish-black shale with some interbedded gray shale	1111	1132
21	Gray shale with some interbedded grayish-black shale	1132	1153
	Bottom of Hatch beds		1153
161	Grayish-black shale (Rhinestreet)	1153	1314
14	Dark-gray shale	1314	1328
7	Grayish-black shale	1328	1335
58	Gray shale	1335	1393
26	Dark-gray shale	1393	1419
	Bottom of Cashaqua shale		1419
35	Black shale	1419	1454
	Bottom of Middlesex shale		1454
7	Brownish-gray, very calcareous shale	1454	1461
5	Gray, very calcareous shale	1461	1466
	Bottom of West River shale		1466
3	Very fine, dense, gray limestone (Genundewa)	1466	1469
	Top of Hamilton group	1469	
26	Gray shale, fossiliferous in lower part	1469	1495
13	Dense brownish-gray fossiliferous limestone with some interbedded gray shale (Tichenor)	1495	1508
69	Dark gray shale	1508	1577
14	Dark-gray shale, somewhat calcareous	1577	1591
14	Very dark gray shale, calcareous	1591	1605
79	Dark-gray shale	1605	1684
14	Dark-gray shale, calcareous	1684	1698
7	Very fine, crystalline, dark brownish-gray limestone	1698	1705
21	Black shale, somewhat calcareous	1705	1726
12	Black shale	1726	1738
21	Dark-gray shale, in part calcareous	1738	1759
7	Dense brownish-gray limestone with interbedded dark gray calcareous shale (Stafford)	1759	1766
14	Very dark gray shale, calcareous	1766	1780
7	Very dark gray shale	1780	1787

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
23	Black shale	1787	1810
	Top of Onondaga limestone	1810	
160	Very fine, crystalline, grayish-brown fossiliferous cherty limestone	1810	1970
	Bottom of Onondaga limestone		1970
6	Very fine, crystalline, grayish-brown siliceous magnesian limestone (Cobleskill)	1970	1976
	Top of Salina group	1976	
47	Very fine, crystalline, light grayish-brown to dark grayish-brown argillaceous magnesian limestone and dolomite (Bertie). Show of gas at 1977; salt water, 1992; and oil, 1997 feet	1976	2023
	Top of Camillus formation	2023	
12	Very fine, crystalline, brownish-gray argillaceous limestone containing a little anhydrite	2023	2035
6	Gray calcareous shale	2035	2041
62	Very fine, crystalline, gray to dark-gray argillaceous limestone containing a little anhydrite	2041	2103
135	Very fine, crystalline, grayish-brown to dark brownish-gray, argillaceous magnesian limestone and dolomite containing a little anhydrite	2103	2238
43	Greenish-gray shale, slightly calcareous	2238	2281
7	Very fine, crystalline, dark brown argillaceous limestone containing a little anhydrite	2281	2288
7	Greenish-gray shale	2288	2295
7	Very fine, crystalline, dark brownish-gray argillaceous limestone	2295	2302
7	Dark greenish-gray shale	2302	2309
52	Very fine, crystalline, dark grayish-brown argillaceous limestone	2309	2361
26	Very fine, crystalline, light brownish-gray argillaceous magnesian limestone	2361	2387
13	Dark grayish-green shale	2387	2400
44	Very fine, crystalline, dark grayish-brown argillaceous magnesian limestone containing some anhydrite	2400	2444
22	Dark greenish-gray shale, slightly calcareous and containing a little anhydrite	2444	2466
	Top of Lockport dolomite	2466	
68	Very fine, crystalline, dark-brown dolomite (show of gas at 2524; considerable salt water at 2531 feet)	2466	2534
104	Very fine, crystalline, dark-brown to very dark grayish-brown magnesian limestone	2534	2638
23	Very fine, crystalline, dark grayish-brown argillaceous limestone	2638	2661
	Top of Clinton group	2661	
43	Dark-gray shale	2661	2704
47	Gray shale, slightly calcareous	2704	2751
	Top of Reynales limestone	2751	
5	Very fine, crystalline, light-gray, magnesian limestone	2751	2756
5	Gray shale, slightly calcareous	2756	2761
5	Very fine, crystalline, light-gray, magnesian limestone	2761	2766
	Bottom of Reynales limestone		2766
6	Greenish-gray shale	2766	2772
	Top of Medina group	2772	
10	Fine-grained, greenish-gray to white sandstone (Thorold)	2772	2782
7	Brick-red sandy shale	2782	2789
14	Fine-grained, brick-red sandstone	2789	2803
14	Brick-red sandy shale	2803	2817
7	Fine-grained, brick-red sandstone	2817	2824
	Bottom of Red Medina (Grimsby)		2824
42	Fine-grained white sandstone	2824	2866
10	Brick-red sandy shale	2866	2876
4	Gray sandy shale	2876	2880
10	Fine-grained white sandstone (25 gallons of salt water per hour at 2884)	2880	2890
	Bottom of White Medina (Whirlpool)		2890
18	Brick-red sandy shale (Queenston)	2890	2908
	Total depth		2908

It is thought that the sandstone encountered at a depth of 42 to 116 feet in the Iroquois Gas Corporation's No. 796 well represents the Laona inasmuch at it occurs at approximately the same elevation as a sandstone forming the highest exposures on Rice Hill west of Boston, which Chadwick has identified as the Laona[81]. Rice Hill is located three miles slightly west of north of Well No. 796. This sandstone lies 667 feet above the horizon that has been identified as the base of the Dunkirk. In the Ryder-Scott deep well in the Bradford district, 40 miles to the south, the interval between the Bradford Third sand and the base of the Dunkirk is 678 feet and in the Quinlan well in the same district, 722 feet. This would seem to verify Chadwick's conclusion that the Bradford Third sand is the equivalent of the Laona sandstone, provided that there is comparatively little thickening of the interval in the intervening distance[82].

Section No. 3

Section No. 3 was obtained in well No. 844 of the Iroquois Gas Corporation, on the L. L. Clark farm, Lot 49, town of Concord, Erie County, New York, 1½ miles north of Springville, and 1459 feet above sea-level. The well was drilled during the summer of 1926. No commercial production of oil or gas was encountered. The following record is based upon the driller's log of the well. No samples of the cuttings were available for examination.

Record of Iroquois Gas Corporation's No. 844 well.

	Depth in feet	
	Top	Bottom
Chemung, Portage, and Hamilton groups, water bearing sandstone encountered at 105 feet	0	1851
Onondaga limestone	1851	2076
Salina group, including Cobleskill limestone, salt at 2470-2488 feet	2076	2624
Lockport dolomite, salt water encountered at 2706 feet	2624	2850
Clinton group	2850	2950
Medina group (Thorold sandstone, 2950-2969)	2950	3060
Queenston shale	3060	3081
Total depth		3081

On the hillside to the west of the Iroquois Gas Corporation's No. 844 well and 70 feet higher, along a small gully, a thin bed of dark chocolate-brown sandstone was at one time quarried on a small scale. Albert M. Nicholson, geologist with the Iroquois Gas Corporation, in 1925, called the attention of the writer to the close lithological resemblance of this sandstone to the Bradford Third of the Bradford district. During a visit to the locality in 1926, the writer measured the following section at the quarry:

	Feet
Thin-bedded gray shale and fine-grained sandstone	3.00
Light-gray, fine-grained, very fossiliferous sandstone	.33
Thin-bedded, fine-grained, gray sandstone and gray shale	4.67
Fine-grained, dark chocolate-brown sandstone (Springville)	2.50
Covered	3.75
Fine-grained, light-gray sandstone	.25
Thin-bedded, fine-grained sandstone and light-gray shale	.58
Fine-grained, light-gray sandstone	.17
Gray shale	.50
Fine-grained, light-gray sandstone	.58
Gray shale	.54
Very fine-grained, dark-brown sandstone	.35
Gray shale	3.25
Covered	2.92
Very fine-grained, light-gray, calcareous sandstone, fossiliferous	.25
Gray shale	1.50

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[81] George H. Chadwick, The stratigraphy of the Chemung group in western New York: New York State Mus. Bull. 251, 1924, p. 151.

[82] Pennsylvania Geological Survey, Fourth Series, Bulletin M. 19, 1933, p. 13.

Iroquois Gas Corporation's No. 844 well is 5½ miles southeast of No. 796. Comparing the records of the two wells, it is found that the water-bearing sandstone encountered at a depth of 105 feet in No. 844 lies 1746 feet above the top of the Onondaga limestone and the sandstone identified as the Laona in No. 796 lies 1694 feet above this horizon. Apparently the water-bearing sandstone in No. 844 also represents the Laona. If this is the case, the Springville sandstone lies about 175 feet above the Laona and about 900 feet above the base of the Dunkirk. It probably does not represent the Bradford Third sand horizon, therefore, but one of the chocolate-colored sandstones above it, possibly the Harrisburg Run.

Section No. 4

Section No. 4 was obtained in a deep well on the L. B. Autman (Hale) farm two miles south of the village of Humphrey in town of Humphrey, Cattaraugus County, New York, drilled during 1929-30 by Hanley and Bird of Bradford, Pennsylvania and the Belmont Quadrangle Drilling Corporation. The top of the well is 1927 feet above sea-level. Drilling started 170 feet below the base of the Cattaraugus red beds. No commercial production of oil or gas was encountered. Enough samples of the cuttings were collected to compile the following somewhat generalized section:

Record of L. B. Autman (Hale) No. 1 well.

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
13	Sand	487	500
30	Sand	525	555
19	Fine-grained grayish-brown sandstone with a little interbedded greenish-gray shale (Humphrey sand)	1567	1586
22	Very fine grained, dark greenish-gray sandstone	2368	2390
	Top of Onondaga limestone	3790	
133	Dark brownish-gray cherty limestone	3790	3923
	Top of Salina group (including Cobleskill limestone)	3923	
210	Very fine, dense, very dark grayish-brown magnesian limestone	3923	4133
12	Very fine, dense, light grayish-brown dolomitic limestone	4133	4145
38	Very fine, dense, very dark grayish-brown magnesian limestone	4145	4183
42	Very fine, crystalline, grayish-brown dolomitic limestone	4183	4225
25	Very fine, dense, light brownish-gray, argillaceous, dolomitic limestone	4225	4250
23	Very fine, crystalline, grayish-brown dolomitic limestone	4250	4273
7	Very fine, crystalline, light brownish-gray argillaceous, dolomitic limestone and anhydrite	4273	4280
10	Gray shale, somewhat calcareous (salt water encountered at 4290 feet)	4280	4290
10	Very fine, crystalline, grayish-brown, argillaceous, magnesian limestone with a little anhydrite	4290	4300
6	Very fine, dense, grayish-brown, argillaceous, dolomitic limestone with some anhydrite	4300	4306
73	Light greenish- and brownish-gray clay, somewhat calcareous, with some interbedded anhydrite and a little salt at 4379 feet	4306	4379
81	Light greenish- and brownish-gray clay, somewhat calcareous, with some interbedded anhydrite	4379	4460
5	Coarse, crystalline, light-gray salt	4460	4465
75	Light greenish- and brownish-gray shale, somewhat calcareous, with some interbedded very fine, dense, brownish-gray, argillaceous, magnesian limestone and very fine, crystalline, light-gray anhydrite (a little salt at 4535 feet)	4465	4540
54	Very fine, dense, brownish-gray, argillaceous, magnesian limestone	4540	4594
8	Purplish-red shale, somewhat calcareous	4594	4602

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
95	Very dark greenish- and brownish-gray shale, somewhat calcareous	4602	4697
	Bottom of Salina group		4697
248	Very fine, crystalline, very dark brownish-gray, dolomitic limestone and dolomite (salt water at 4793 feet)	4697	4945
	Bottom of Lockport dolomite		4945
75	Dark-gray shale with considerable interbedded very fine, dense, dark-gray, argillaceous, magnesian limestone	4945	5020
8	Very fine, crystalline, greenish-gray dolomitic limestone	5020	5028
37	Greenish-gray shale with a little very fine, crystalline, very dark brownish-gray limestone at 5050 feet	5028	5065
	Bottom of Clinton group		5065
6	Fine-grained greenish-gray sandstone, somewhat calcareous (Thorold)	5065	5071
4	Fine-grained red sandstone	5071	5075
3	Dark brick-red sandy shale	5075	5078
3	Fine-grained light-gray sandstone	5078	5081
2	Brick-red sandy shale	5081	5083
3	Fine-grained light-gray sandstone	5083	5086
3	Dark brick-red sandy shale	5086	5089
28	Fine-grained, light-gray sandstone with a little interbedded pink and red sandstone	5089	5117
2	Purplish-gray shale	5117	5119
	Bottom of Red Medina (Grimsby)		5119
13	Fine-grained light-gray sandstone with a little interbedded light-pink sandstone	5119	5132
1	Greenish-gray shale	5132	5133
4	Fine-grained light-gray sandstone	5133	5137
4	Greenish-gray sandy shale	5137	5141
5	Fine-grained light-gray sandstone	5141	5146
1	Greenish-gray shale	5146	5147
22	Fine-grained light-gray sandstone	5147	5169
1	Purplish-gray sandy shale	5169	5170
8	Fine-grained light-gray sandstone	5170	5178
	Bottom of White Medina (Whirlpool)		5178
12	Dark brick-red sandy shale	5178	5190
10	Dark brick-red shale	5190	5200
28	Dark brick-red sandy shale	5200	5228
12	Dark brick-red shale	5228	5240
67	Dark brick-red sandy shale	5240	5307
	Well stopped in Queenston red shale at a total depth of		5307

Inasmuch as only a few samples of the cuttings were collected above the Onondaga limestone in the Autman well, it has not been possible to delimit the Chemung, Portage and Hamilton groups. A sandstone encountered at a depth of 1567 to 1586 feet, which has produced some oil in a small pool 1½ miles northwest of the Autman well, has been incorrectly correlated with the Bradford[83], which it resembles somewhat, lithologically. The Humphrey sand lies 1737 feet below the base of the Cattaraugus formation, while in the Derrick City well, 15 miles to the south, the interval between the base of the Cattaraugus formation and the top of the Bradford sand is only 1245 feet.

Section No. 5

Section No. 5 was obtained in J. Brooke Reed's Quinlan No. 1 well, near the head of Indian Creek, one mile north of the New York-Pennsylvania line in the Town of Olean, Cattaraugus County, New York, at an elevation of 1686 feet above sea-level. The well was completed during the latter part of 1933. A good show of oil was found in the Oriskany sandstone. The following record is based on an examination of a complete set of samples of the cuttings:

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[83] Irving P. Bishop, Oil and natural gas in Cattaraugus Co.; New York State Mus., 51st Ann. Report, 1897, vol. 2, 1899, p. 40.

Record of J. Brooke Reed's Quinlan No. 1 Well

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
30	No samples	0	30
32	Very fine grained greenish-gray sandstone with some interbedded greenish-gray sandy shale in lower part	30	62
27	Greenish-gray sandy shale with some interbedded very fine grained greenish-gray sandstone	62	89
2	Very fine grained brownish-gray sandstone	89	91
18	Greenish-gray sandy shale	91	109
19	Very fine grained greenish-gray sandstone with some interbedded greenish-gray sandy shale	109	128
26	Greenish-gray sandy shale, fossiliferous, with some interbedded very fine grained greenish-gray sandy shale	128	154
17	Very fine grained greenish-gray sandstone, slightly calcareous, with some interbedded greenish-gray sandy shale	154	171
23	Very fine grained grayish-brown sandstone with some interbedded greenish-gray sandy shale	171	194
12	Very fine grained greenish-gray sandstone with some interbedded greenish-gray sandy shale	194	206
5	Greenish-gray sandy shale	206	211
6	Very fine grained greenish-gray sandstone	211	217
6	Very fine grained brown sandstone	217	223
5	Very fine grained greenish-gray sandstone with some interbedded greenish-gray sandy shale	223	228
12	Greenish-gray sandy shale with some very fine grained light brownish-gray and greenish-gray sandstone	228	240
12	Very fine grained greenish-gray sandstone, slightly calcareous, with some interbedded greenish-gray sandy shale	240	252
6	Greenish-gray sandy shale	252	258
	Top of Hinsdale sandstone	258	
11	Very fine grained dark grayish-brown sandstone with a little interbedded greenish-gray sandy shale	258	269
11	Very fine grained greenish-gray sandstone with a little interbedded greenish-gray sandy shale	269	280
6	Very fine grained dark grayish-brown sandstone with some interbedded dark greenish-gray sandy shale	280	286
	Bottom of Hinsdale sandstone and Chadakoin beds		286
16	Gray sandy shale, fossiliferous	286	302
5	Very fine grained greenish-gray sandstone with some interbedded gray shale	302	307
47	Greenish-gray sandy shale	307	354
18	Very fine grained greenish-gray sandstone with some interbedded greenish-gray sandy shale (casing set at 360 feet	354	372
5	Gray shale	372	377
58	Greenish-gray sandy shale	377	435
6	Very fine grained greenish-gray sandstone	435	441
6	Greenish-gray sandy shale	441	447
6	Gray shale	447	453
6	Greenish-gray sandy shale	453	459
5	Greenish-gray shale	459	464
12	Greenish-gray sandy shale, very fossiliferous in upper part	464	476
5	Greenish-gray shale	476	481
25	Greenish-gray sandy shale, fossiliferous	481	506
6	Fine-grained greenish-gray sandstone, slightly calcareous (Bradford First, Cuba)	506	512
	Bottom of Girard beds		512
12	Greenish-gray sandy shale	512	524
12	Greenish-gray shale	524	536
14	Greenish-gray sandy shale	536	550
4	Very fine grained light greenish-gray sandstone, somewhat calcareous, fossiliferous	550	554
16	Gray shale	554	570
6	Dark greenish-gray sandy shale, fossiliferous	570	576
18	Gray shale	576	594
9	Fine-grained light-gray sandstone (Sugar Run)	594	603
15	Gray shale	603	618
6	Greenish-gray sandy shale	618	624
19	Greenish-gray shale	624	643
7	Greenish-gray sandy shale with some interbedded very fine grained brownish and greenish-gray sandstone	643	650

Thickness feet	Description of strata	Depth in feet Top	Bottom
24	Gray shale	650	674
6	Very fine grained greenish-gray sandstone	674	680
13	Gray shale, in part sandy	680	693
12	Fine-grained light brownish-gray sandstone, somewhat calcareous in upper part (Chipmunk)	693	705
31	Greenish-gray shale with some interbedded very fine grained light brownish and greenish-gray sandstone	705	736
48	Greenish-gray shale	736	784
6	Greenish-gray sandy shale, fossiliferous	784	790
6	Very fine grained greenish-gray sandstone, slightly calcareous, with some interbedded greenish-gray shale	790	796
47	Gray shale	796	843
	Top of Bradford Second Sand	843	
5	Very fine grained light brownish-gray sandstone, slightly calcareous	843	848
17	Very fine grained grayish-brown sandstone, slightly calcareous, with a little interbedded greenish-gray shale	848	865
18	Very fine grained grayish-brown sandstone with a little interbedded gray shale	865	883
6	Very fine grained grayish-brown and greenish-gray sandstone	883	889
6	Very fine grained brownish-gray sandstone with some interbedded gray sandy shale	889	895
10	Very fine grained brownish-gray sandstone, slightly calcareous, with a little interbedded gray shale	895	905
	Bottom of Bradford Second sand and Northeast beds		905
6	Gray sandy shale	905	911
10	Gray and greenish-gray shale	911	921
37	Gray sandy shale	921	958
3	Very fine grained grayish-brown sandstone, slightly calcareous (Harrisburg Run)	958	961
28	Gray sandy shale	961	989
7	Gray shale	989	996
7	Gray sandy shale	996	1003
11	Gray shale	1003	1014
26	Gray sandy shale, fossiliferous in upper part	1014	1040
7	Gray shale	1040	1047
12	Gray sandy shale	1047	1059
31	Gray shale	1059	1090
8	Greenish-gray sandy shale, fossiliferous	1090	1098
40	Gray shale	1098	1138
2	Very fine grained light-gray sandstone, calcareous, very fossiliferous	1138	1140
	Top of Bradford Third sand	1140	
17	Fine-grained light grayish-brown sandstone, gas sand, with a little interbedded greenish-gray shale	1140	1157
28	Fine-grained light brownish-gray sandstone, gas sand	1157	1185
6	Fine-grained grayish-brown sandstone, oil sand, with some interbedded greenish-gray shale	1185	1191
8	Fine-grained grayish-brown sandstone, oil sand	1191	1199
10	Fine-grained grayish-brown sandstone, oil sand, with considerable interbedded greenish-gray shale	1199	1209
49	Fine-grained grayish-brown sandstone, oil sand, with some interbedded greenish-gray shale	1209	1258
	Bottom of Bradford Third sand and Westfield beds		1258
8	Greenish-gray shale with a little interbedded grayish-brown sandstone	1258	1266
15	Gray shale	1266	1281
18	Gray shale with a little interbedded grayish-brown sandstone	1281	1299
6	Gray shale	1299	1305
40	Gray shale with a little interbedded very fine grained light-gray sandstone	1305	1345
79	Gray shale	1345	1424
	Top of Kane sand	1424	
10	Very fine grained chocolate-brown sandstone	1424	1434
36	Gray shale	1434	1470
16	Very fine grained grayish-brown sandstone, slightly calcareous, good show of oil, with some interbedded gray shale	1470	1486
7	Very fine grained dark grayish-brown sandstone, good show of oil	1486	1493

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
	Bottom of Kane sand		1493
21	Gray sandy shale	1493	1514
29	Dark gray sandy shale	1514	1543
13	Gray shale	1543	1556
13	Gray sandy shale	1556	1569
14	Gray shale	1569	1583
6	Dark gray sandy shale	1583	1589
61	Gray shale	1589	1650
8	Gray sandy shale	1650	1658
34	Gray and dark gray shale	1658	1692
11	Gray sandy shale	1692	1703
	Top of Humphrey sand	1703	
3	Very fine grained chocolate-brown sandstone	1703	1706
11	Gray sandy shale	1706	1717
11	Very fine grained light greenish-gray sandstone, slightly calcareous, show of oil, with some interbedded gray shale	1717	1728
	Bottom of Humphrey sand		1728
8	Gray shale	1728	1736
6	Gray sandy shale	1736	1742
27	Gray shale	1742	1769
	Bottom of Gowanda beds		1769
28	Very dark gray, almost black, sandy shale with some interbedded gray shale	1769	1797
8	Greenish-gray sandy shale	1797	1805
8	Very dark gray sandy shale	1805	1813
23	Greenish-gray sandy shale	1813	1836
8	Very fine grained chocolate-brown sandstone	1836	1844
15	Gray shale	1844	1859
3	Very fine grained grayish-brown sandstone	1859	1862
24	Gray shale in part sandy	1862	1886
17	Dark to very dark gray sandy shale	1886	1903
24	Greenish-gray sandy shale with some interbedded grayish-black sandy shale	1903	1927
8	Grayish-black sandy shale with some interbedded gray shale	1927	1935
8	Gray shale	1935	1943
17	Gray to dark-gray sandy shale	1943	1960
8	Dark-gray shale	1960	1968
12	Very fine grained greenish-gray sandstone, small show of oil	1968	1980
	Bottom of Dunkirk beds and Chemung group		1980
27	Greenish-gray sandy shale	1980	2007
8	Very dark gray, almost black, shale	2007	2015
47	Dark-gray sandy shale	2015	2062
17	Dark-gray shale	2062	2079
52	Greenish-gray sandy shale with some interbedded grayish-black shale in lower part	2079	2131
15	Gray shale	2131	2146
7	Grayish-black shale	2146	2153
19	Greenish-gray sandy shale	2153	2172
	Bottom of Wiscoy beds		2172
40	Very fine grained greenish-gray sandstone with some interbedded gray shale	2172	2212
11	Greenish-gray shale with some interbedded very fine grained brownish-gray sandstone	2212	2223
27	Greenish-gray sandy shale	2223	2250
50	Very fine grained brownish-gray sandstone with some interbedded gray shale	2250	2300
8	Very fine grained greenish-gray sandstone	2300	2308
6	Dark-gray sandy shale	2308	2314
12	Very fine grained greenish-gray sandstone	2314	2326
6	Dark-gray sandy shale	2326	2332
6	Very fine grained light greenish-gray sandstone	2332	2338
32	Dark-gray shale with a little interbedded greenish-gray sandy shale	2338	2370
6	Greenish-gray sandy shale	2370	2376
6	Very fine grained greenish-gray sandstone	2376	2382
	Bottom of Nunda beds		2382
6	Dark greenish-gray sandy shale	2382	2388
116	Dark-gray shale	2388	2504
6	Dark greenish-gray sandy shale	2504	2510
23	Dark-gray shale	2510	2533
5	Brownish-gray sandy shale	2533	2538
18	Gray sandy shale	2538	2556
17	Gray shale	2556	2573
39	Gray sandy shale	2573	2612
20	Gray shale	2612	2632
12	Gray sandy shale	2632	2644

Thickness feet	Description of strata	Depth in feet Top	Bottom
13	Gray shale	2644	2657
9	Gray sandy shale	2657	2666
8	Gray shale	2666	2674
10	Gray sandy shale	2674	2684
35	Gray shale	2684	2719
	Bottom of Gardeau beds		2719
12	Very fine grained gray sandstone (Grimes)	2719	2731
6	Gray shale	2731	2737
4	Gray sandy shale	2737	2741
7	Gray shale	2741	2748
5	Very fine grained gray sandstone with some interbedded gray shale	2748	2753
14	Very fine grained brownish-gray to dark grayish-brown sandstone with some interbedded gray shale	2753	2767
5	Gray shale	2767	2772
5	Very fine grained gray sandstone	2772	2777
5	Gray shale	2777	2782
12	Gray sandy shale	2782	2794
6	Gray shale	2794	2800
12	Very fine grained chocolate-brown sandstone	2800	2812
20	Gray shale	2812	2832
9	Gray sandy shale	2832	2841
10	Very fine grained chocolate-brown sandstone with some interbedded gray sandy shale	2841	2851
46	Gray to dark-gray shale	2851	2897
29	Grayish-black shale	2897	2926
10	Gray sandy shale	2926	2936
10	Gray to dark-gray shale	2936	2946
15	Gray sandy shale	2946	2961
31	Gray to very dark gray shale	2961	2992
25	Dark-gray sandy shale	2992	3017
9	Grayish-black shale	3017	3026
11	Gray sandy shale	3026	3037
45	Gray to very dark gray shale	3037	3082
53	Gray shale with a little interbedded grayish-black shale	3082	3135
	Bottom of Hatch beds		3135
19	Grayish-black shale with some interbedded gray shale	3135	3154
29	Gray to very dark gray shale	3154	3183
81	Gray shale with a little interbedded grayish-black shale	3183	3264
10	Grayish-black shale	3264	3274
	Bottom of Rhinestreet black shale		3274
106	Dark-gray shale	3274	3380
76	Gray shale, slightly calcareous	3380	3456
13	Dark-gray shale	3456	3469
	Bottom of Cashaqua shale		3469
7	Grayish-black shale	3469	3476
12	Gray shale with some interbedded grayish-black shale	3476	3488
54	Very dark gray shale	3488	3542
8	Grayish-black shale	3542	3550
	Bottom of Middlesex black shale		3550
8	Very dark gray shale	3550	3558
17	Grayish-black shale	3558	3575
41	Dark-gray shale	3575	3616
	Bottom of West River shale		3616
2	Very fine, dense, dark grayish-brown limestone (Genundewa)	3616	3618
	Bottom of Portage group		3618
7	Dark-gray, slightly calcareous	3618	3625
16	Very dark gray shale, slightly calcareous	3625	3641
7	Very dark brownish-gray calcareous shale	3641	3648
13	Very dark gray shale, somewhat calcareous	3648	3661
10	Very dark gray calcareous shale	3661	3671
14	Very dark gray shale, somewhat calcareous	3671	3685
14	Dark-gray shale	3685	3699
15	Grayish-black shale	3699	3714
12	Gray shale	3714	3726
17	Grayish-black shale	3726	3743
	Bottom of Genesee black shale		3743
5	Very fine dense brownish-gray limestone (Tully)	3743	3748
	Top of Hamilton group	3748	
51	Dark-gray shale, slightly calcareous	3748	3799
1	Very fine dense brownish-gray limestone (Tichenor)	3799	3800
35	Dark-gray shale, somewhat calcareous	3800	3835

Thickness feet	Description of strata	Depth in feet Top	Bottom
25	Dark-gray shale, slightly calcareous	3835	3860
42	Dark-gray shale, somewhat calcareous	3860	3902
21	Dark-gray calcareous shale	3902	3923
29	Dark-gray shale, somewhat calcareous	3923	3952
14	Dark-gray shale, slightly calcareous	3952	3966
28	Dark-gray shale, somewhat calcareous	3966	3994
22	Very dark gray shale, somewhat calcareous	3994	4016
84	Dark-gray shale, somewhat calcareous	4016	4100
17	Grayish-black shale, somewhat calcareous	4100	4117
25	Very dark gray shale, somewhat calcareous	4117	4142
33	Black shale, somewhat calcareous	4142	4175
	Top of Onondaga limestone	4175	
6	Very fine, crystalline, brownish-gray limestone	4175	4181
40	Fine, crystalline, very light brownish-gray limestone	4181	4221
39	Fine, crystalline, white limestone, containing a little chert	4221	4260
10	Fine, crystalline, very light brownish-gray cherty limestone	4260	4270
6	Very fine, dense, brownish-gray, cherty, fossiliferous limestone	4270	4276
	Top of Oriskany	4276	
5	Fine- to medium-grained dark grayish-brown sandstone, somewhat calcareous (good show of oil)	4276	4281
7	Fine- to medium-grained light-gray sandstone, somewhat calcareous	4281	4288
3	Fine- to medium-grained light-gray sandstone. Some of grains rounded and frosted, others show crystal facets, somewhat calcareous (good show of oil)	4288	4291
	Top of Helderberg group	4291	
5	Very fine, crystalline, dark grayish-brown limestone	4291	4296
	Total depth		4296

Section No. 6

Section No. 6 was obtained in the Ryder-Scott No. 1 well of J. Brooke Reed and associates, located near the head of Chipmunk Creek in the Town of Allegany, Cattaraugus County, New York, 1.2 miles north of the New York-Pennsylvania line, at an elevation of 1876 feet. It started in the Cattauraugus formation of the Upper Devonian and reached the bottom of the Oriskany sandstone. The well was completed during the early part of 1934. No fluids, either gas, oil, or water, were encountered in the Oriskany. The following record is based on examination of a complete set of samples of the cuttings:

Record of J. Brooke Reed's Ryder-Scott No. 1 Well

Thickness feet	Description of strata	Depth in feet Top	Bottom
15	No samples	0	15
49	Fine-grained grayish-green sandstone with some interbedded brick-red sandy shale in lower part	15	64
14	Greenish-gray sandy shale	64	78
16	Greenish-gray shale	78	94
5	Greenish-gray sandy shale	94	99
6	Medium- to coarse-grained light greenish-gray sandstone with some well rounded quartz grains up to 2 mm. in diameter (Wolf Creek)	99	105
	Bottom of Cattaraugus formation		105
16	Greenish-gray sandy shale	105	121
28	Greenish-gray shale, fossiliferous in lower part	121	149
25	Greenish-gray sandy shale	149	174
11	Greenish-gray shale, fossiliferous, with some interbedded purplish-gray sandy shale	174	185
35	Greenish-gray sandy shale	185	220
10	Greenish-gray shale	220	230
11	Dark greenish-gray sandy shale	230	241
5	Greenish-gray shale	241	246

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
6	Greenish-gray sandy shale	246	252
12	Dark greenish-gray shale with some interbedded grayish-green sandy shale	252	264
6	Greenish-gray sandy shale	264	270
12	Greenish-gray sandy shale with some interbedded purplish-gray sandy shale	270	282
23	Greenish-gray sandy shale, fossiliferous	282	305
6	Very fine grained dark greenish-gray sandstone with some interbedded dark greenish-gray shale	305	311
6	Dark greenish-gray shale, fossiliferous, with some interbedded dark purplish-gray sandy shale	311	317
16	Greenish-gray sandy shale, fossiliferous	317	333
16	Grayish-purple sandy shale	333	349
5	Greenish-gray sandy shale, fossiliferous, with some interbedded grayish-purple sandy shale	349	354
5	Dark greenish-gray sandy shale	354	359
16	Greenish-gray shale	359	375
10	Very fine grained light greenish-gray sandstone, very fossiliferous	375	385
23	Grayish-purple sandy shale and shale with some interbedded greenish-gray shale	385	408
5	Greenish-gray sandy shale	408	413
55	Grayish-purple sandy shale with some interbedded greenish-gray shale	413	468
18	Very fine grained light greenish-gray sandstone, fossiliferous, with some interbedded greenish-gray and purplish-gray shale (Hinsdale)	468	486
	Bottom of Chadakoin beds		486
48	Greenish-gray shale	486	534
6	Greenish-gray sandy shale	534	540
6	Dark greenish-gray shale	540	546
6	Greenish-gray sandy shale, fossiliferous	546	552
11	Greenish-gray shale with some interbedded greenish-gray sandy shale	552	563
20	Dark greenish-gray shale with some interbedded greenish-gray sandy shale	563	583
5	Very fine grained greenish-gray sandstone, fossiliferous	583	588
15	Dark greenish-gray shale	588	603
2	Very fine grained greenish-gray sandstone, fossiliferous	603	605
23	Dark greenish-gray shale with some interbedded dark greenish-gray sandy shale, fossiliferous	605	628
3	Fine-grained reddish-brown ferruginous sandstone, slightly calcareous	628	631
20	Interbedded dark greenish-gray shale and sandy shale	631	651
10	Greenish-gray shale	651	661
10	Dark greenish-gray sandy shale, fossiliferous	661	671
12	Dark greenish-gray shale with some interbedded greenish-gray sandy shale	671	683
12	Greenish-gray sandy shale, very fossiliferous	683	695
8	Greenish-gray shale	695	703
8	Greenish-gray sandy shale, very fossiliferous	703	711
4	Very fine grained light greenish-gray sandstone, very fossiliferous	711	715
18	Dark greenish-gray shale	715	733
18	Very fine grained light greenish-gray sandstone, somewhat calcareous in lower part, with some interbedded greenish-gray shale	733	751
15	Greenish-gray to dark-gray shale	751	766
5	Dark greenish-gray sandy shale	766	771
12	Dark-gray shale	771	783
10	Medium- to coarse-grained white sandstone with quartz grains up to 2 mm. in diameter, somewhat calcareous in upper part; salt water encountered in this sand—(Bradford First sand—Cuba)	783	793
	Bottom of Girard beds		793
26	Greenish-gray sandy shale	793	819
17	Greenish-gray shale	819	836
10	Greenish-gray sandy shale	836	846
9	Very fine grained pale grayish-brown sandstone, fossiliferous, with some interbedded greenish-gray shale	846	855
8	Fine grained light-gray sandstone, fossiliferous, with some interbedded greenish-gray shale (Sugar Run)	855	863
8	Greenish-gray shale	863	871

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
8	Fine grained light greenish-gray sandstone with some interbedded greenish-gray shale	871	879
48	Greenish-gray shale with some interbedded greenish gray sandy shale	879	927
7	Fine grained light-gray sandstone, slightly calcareous	927	934
12	Gray shale with some interbedded fine-grained light-gray sandstone, slightly calcareous	934	946
51	Greenish-gray shale	946	997
	Top of Chipmunk sand	997	
4	Fine-grained light grayish-brown sandstone	997	1001
5	Dark greenish-gray shale	1001	1006
38	Fine-grained light grayish-brown sandstone with a little interbedded gray shale	1006	1044
	Bottom of Chipmunk sand		1044
81	Greenish-gray shale, in part sandy	1044	1125
	Top of Bradford Second sand	1125	
4	Fine-grained chocolate-brown sandstone	1125	1129
7	Greenish-gray shale	1129	1136
6	Greenish-gray sandy shale with a little interbedded fine-grained light greenish-gray sandstone	1136	1142
14	Very fine grained chocolate-brown sandstone, slightly calcareous, with some interbedded greenish-gray shale	1142	1156
	Bottom of Bradford Second sand and of Northeast beds		1156
35	Greenish-gray shale with some interbedded very fossiliferous greenish-gray sandy shale in lower part	1156	1191
9	Very fine grained grayish-brown sandstone, somewhat calcareous (Harrisburg Run)	1191	1200
33	Greenish-gray shale	1200	1233
31	Interbedded greenish-gray sandy shale and shale, fossiliferous	1233	1264
41	Greenish-gray shale	1264	1305
8	Greenish-gray sandy shale	1305	1313
70	Greenish-gray shale	1313	1383
20	Greenish-gray sandy shale, fossiliferous	1383	1403
16	Greenish-gray shale	1403	1419
91	Interbedded very fine grained grayish-brown sandstone and greenish-gray shale (Bradford Third sand)	1419	1510
	Bottom of Westfield beds		1510
105	Greenish-gray shale with a little interbedded very fine grained grayish-brown and light greenish-gray sandstone	1510	1615
73	Greenish-gray shale with some interbedded greenish-gray sandy shale	1615	1688
8	Very fine grained brown sandstone, slightly calcareous, with a great deal of interbedded greenish-gray shale (Kane)	1688	1696
21	Gray sandy shale	1696	1717
38	Gray shale	1717	1755
36	Gray to dark-gray sandy shale	1755	1791
8	Dark brownish-gray sandy shale	1791	1799
42	Gray to dark-gray shale	1799	1841
27	Greenish-gray shale with some interbedded greenish-gray sandy shale, fossiliferous	1841	1868
41	Gray shale	1868	1909
9	Gray sandy shale	1909	1918
8	Gray shale	1918	1926
12	Very fine grained light greenish-gray sandstone with a little interbedded gray shale (Humphrey)	1926	1938
25	Gray to very dark gray shale	1938	1963
15	Greenish to dark greenish-gray sandy shale	1963	1978
	Bottom of Gowanda beds		1978
25	Gray shale with a little interbedded very dark gray shale	1978	2003
9	Very dark gray shale	2003	2012
19	Gray shale	2012	2031
17	Very dark gray sandy shale	2031	2048
17	Gray shale	2048	2065
9	Gray sandy shale	2065	2074
9	Gray shale with a little interbedded very fine grained light-gray sandstone	2074	2088
8	Gray sandy shale	2083	2091
7	Gray shale with some interbedded grayish-black shale	2091	2098

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
27	Gray sandy shale with some interbedded gray shale	2098	2125
15	Gray shale with some interbedded dark-gray shale	2125	2140
20	Gray to very dark gray sandy shale	2140	2160
8	Gray shale	2160	2168
20	Grayish-black shale with some interbedded gray sandy shale	2168	2188
	Bottom of Dunkirk black shale and of Chemung group		2188
6	Gray shale with a little interbedded grayish-black shale	2188	2194
9	Dark-gray sandy shale with some interbedded gray shale	2194	2203
43	Greenish-gray sandy shale with a little interbedded very dark gray shale	2203	2246
9	Greenish-gray sandy shale with some interbedded grayish-black shale	2246	2255
32	Greenish-gray sandy shale	2255	2287
51	Gray shale with a little interbedded gray to dark-gray sandy shale	2287	2338
11	Very dark gray, almost black, shale	2338	2349
5	Very fine grained light-gray sandstone with considerable interbedded grayish-black shale	2349	2354
9	Dark-gray sandy shale with a little very fine grained gray sandstone, somewhat calcareous	2354	2363
14	Dark-gray to very dark gray, almost black, shale with some interbedded gray sandy shale	2363	2377
7	Black shale with a little interbedded very fine grained light greenish-gray sandstone, slightly calcareous	2377	2384
9	Light greenish-gray sandy shale	2384	2393
	Bottom of Wiscoy beds		2393
5	Very fine grained greenish-gray sandstone, slightly calcareous	2393	2398
29	Greenish-gray sandy shale	2398	2427
7	Very fine grained greenish-gray sandstone, slightly calcareous	2427	2434
4	Gray shale	2434	2438
15	Greenish-gray sandy shale with some interbedded gray shale	2438	2453
5	Dark greenish-gray shale	2453	2458
10	Gray shale	2458	2468
7	Very fine grained greenish-gray sandstone, slightly calcareous, with some interbedded dark-gray shale	2468	2475
8	Gray shale	2475	2483
9	Greenish-gray sandy shale	2483	2492
9	Very fine grained light greenish-gray sandstone	2492	2501
18	Greenish-gray sandy shale	2501	2519
9	Gray shale	2519	2528
24	Very fine grained light greenish-gray sandstone with some interbedded grayish-black shale	2528	2552
	Bottom of Nunda beds		2552
7	Greenish-gray sandy shale	2552	2559
28	Gray to dark-gray sandy shale	2559	2587
8	Gray shale	2587	2595
55	Greenish-gray sandy shale	2595	2650
80	Dark-gray shale	2650	2730
8	Greenish-gray sandy shale	2730	2738
8	Dark-gray shale	2738	2746
17	Greenish-gray sandy shale, small show of gas	2746	2763
11	Dark-gray shale with a little interbedded grayish-black shale	2763	2774
6	Greenish-gray sandy shale	2774	2780
15	Dark-gray shale with some interbedded dark greenish-gray sandy shale	2780	2795
	Bottom of Gardeau beds		2795
7	Very fine grained greenish-gray sandstone (Grimes)	2795	2802
10	Gray shale	2802	2812
23	Greenish to dark greenish-gray shale	2812	2835
50	Gray shale	2835	2885
9	Gray shale with some interbedded grayish-black shale	2885	2894
45	Gray to very dark gray shale	2894	2939
13	Very fine grained brownish-gray sandstone, slightly calcareous	2939	2952
11	Dark-gray shale	2952	2963
5	Very fine grained gray sandstone	2963	2968

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
10	Very fine grained brownish-gray sandstone	2968	2978
56	Dark-gray shale with a little interbedded very fine grained gray sandstone	2978	3034
14	Dark-gray shale with some interbedded grayish-black shale	3034	3048
30	Dark-gray shale with a little interbedded very fine grained gray sandstone	3048	3078
32	Grayish-black shale	3078	3110
63	Gray to dark-gray shale	3110	3173
20	Grayish-black shale	3173	3193
11	Gray to dark-gray shale	3193	3204
5	Grayish-black shale	3204	3209
20	Dark-gray shale	3209	3229
	Bottom of Hatch beds		3229
40	Grayish-black shale with a little interbedded dark-gray shale	3229	3269
34	Gray to dark-gray shale	3269	3303
18	Grayish-black shale with some interbedded gray shale	3303	3321
	Bottom of Rhinestreet black shale		3321
74	Dark-gray shale	3321	3395
121	Dark-gray shale, slightly calcareous	3395	3516
26	Very dark gray shale, slightly calcareous	3516	3542
	Bottom of Cashaqua shale		3542
5	Grayish-black shale	3542	3547
10	Very dark gray shale	3547	3557
101	Grayish-black shale	3557	3658
	Bottom of Middlesex black shale		3658
29	Very dark gray shale, slightly calcareous	3658	3687
17	Very dark gray, almost black, shale, somewhat calcareous	3687	3704
	Bottom of West River shale and of Portage group		3704
34	Black shale, calcareous	3704	3738
12	Black shale, slightly calcareous	3738	3750
13	Grayish-black shale	3750	3763
18	Black shale, slightly calcareous	3763	3781
	Bottom of Genesee black shale		3781
4	Very fine dense grayish-brown limestone (Tully)	3781	3785
	Top of Hamilton group	3785	
36	Very dark gray shale, somewhat calcareous	3785	3821
18	Dark to very dark gray shale, slightly calcareous	3821	3839
2	Very fine, dense, light brownish-gray limestone, very fossiliferous (Tichenor)	3839	3841
51	Very dark gray shale, somewhat calcareous	3841	3892
24	Very dark gray shale, calcareous	3892	3916
3	Very fine, dense, grayish-brown limestone	3916	3919
23	Dark to very dark gray shale, calcareous	3919	3942
20	Dark to very dark gray shale, somewhat calcareous	3942	3962
6	Very dark gray shale, calcareous	3962	3968
27	Grayish-black shale, somewhat calcareous	3968	3995
6	Grayish-black shale, calcareous	3995	4001
41	Very dark gray shale, somewhat calcareous	4001	4042
39	Grayish-black shale, somewhat calcareous	4042	4081
2	Very fine dense, grayish-brown limestone (Center Field)	4081	4083
60	Grayish-black shale, somewhat calcareous	4083	4143
19	Dark gray shale, somewhat calcareous	4143	4162
15	Very dark gray shale, calcareous	4162	4177
19	Dark to very dark gray shale, somewhat calcareous	4177	4196
35	Black shale, calcareous	4196	4231
22	Black shale, somewhat calcareous	4231	4253
1	Very fine, dense, grayish-brown limestone	4253	4354
15	Black shale	4254	4269
6	Black shale, calcareous	4269	4375
	Top of Onondaga limestone	4275	
8	Very fine, crystalline, dark grayish-brown limestone	4275	4283
57	Very fine dense, very dark grayish-brown limestone—gas pocket at 4304—4306	4283	4340
13	Very fine, crystalline, light brownish-gray cherty limestone	4340	4353
	Top of Oriskany sandstone	4353	
7	Medium-grained light-gray sandstone, calcareous	4353	4360
3	Medium-grained light-gray sandstone, slightly calcareous	4360	4363

Thickness feet	Description of strata	Depth in feet Top	Bottom
7	Medium-grained light-gray sandstone, somewhat calcareous	4363	4370
	Total depth		4370

The Ryder-Scott deep well is located on the northern margin of the Bradford oil pool, the type locality for the Bradford Third sand, the main producing horizon of the Bradford field, as well as for the Bradford first and Second sands. The Bradford First sand in the vicinity of the well contains much salt water that has to be cased off. The Chipmunk oil pool, the type locality for the Chipmunk sand, is located along Chipmunk Creek about two miles to the northwest. Oil production is obtained from both the Chipmunk and Bradford Second sands at the head of Nichol Run about one mile to the west of the well.

Section No. 7

The Bradford Deep Well Company drilled a well at Derrick City, Foster Township, McKean County, Pennsylvania, during 1912 to 1914 which reached the Queenston shale. The well started 1576 feet above sea-level at a horizon 125 feet below the base of the Cattaraugus formation. No commercial production of oil or gas was encountered below the Bradford sand. A show of oil was reported from the Oriskany sandstone. The following correlations of the strata passed through are based upon the drillers' log published by White[84] and an examination of a partial set of samples of cuttings on file at the office of L. E. Mallory in Bradford, Pa.

Record of Derrick City Deep Well

	Depth in feet Top	Bottom
Chemung and Portage groups	0	3400
Bradford sand, 1120-1198		
Haskell sand, 1550-1570		
Genesee black shale	3400	3575
Hamilton group	3575	4065
Onondaga limestone	4065	4135
Oriskany sandstone (show of oil)	4135	4155
Helderberg limestone	4155	4215
Cobleskill limestone	4215	4235
Salina group	4235	5085
Bertie water lime, 4235-4265		
Salt 4490-4520		
Salt 4596-4606		
Salt 4638-4685		
Salt 4693-4713		
Lockport dolomite	5085	5385
Clinton group	5385	5560
Medina group	5560	5700
Red Medina, 5560-5642		
White Medina, 5642-5700		

Well stopped in Queenston red shale at a total depth of 5820 feet.

Section No. 8

Section No. 8 was obtained in the Potter Development Company's No. 1165 well, located on the Zerbe farm, 3½ miles west of Port Allegany, Liberty Township, McKean County, Pennsylvania. The well started 1751 feet above sea-level at a horizon 140 feet below the base of the Cattaraugus formation.

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[84] I. C. White, Discussion of the records of some very deep wells in the Appalachian Oil Fields of Pennsylvania, Ohio, and West Virginia. Barbour and Upshur Counties and Western Portion of Randolph County Report, West Virginia Geo. Survey, pages XXXII to XXXVII, 1918.

On August 1, 1934, it had reached a depth of 5125 feet in beds of Salina age. The Oriskany sandstone was absent at this locality. A complete set of samples of the cuttings from this well, with the exception of the intervals from 0 to 705 feet and 4288 to 4682 feet, was available for examination.

Record of the Zerbe well

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
705	No samples	0	705
	Top of Chipmunk sand	705	
12	Fine-grained light greenish-gray sandstone, fossiliferous and slightly calcareous, with some interbedded greenish-gray sandy shale	705	717
15	Greenish-gray sandy shale, with some interbedded fine-grained light greenish-gray sandstone	717	732
32	Fine-grained light greenish-gray sandstone, with some interbedded greenish-gray shale	732	764
	Bottom of Chipmunk sand		764
10	Greenish-gray sandy shale, with some interbedded fine-grained light greenish-gray sandstone	764	774
6	Greenish-gray shale, with some interbedded fine-grained light greenish-gray sandstone, fossiliferous	774	780
35	Dark greenish-gray shale	780	815
15	Fine-grained light greenish-gray sandstone, somewhat calcareous and fossiliferous, with some interbedded dark greenish-gray shale (Bradford Second)	815	830
47	Dark greenish-gray shale, with a little interbedded fine-grained grayish-brown sandstone, in part fossiliferous	830	877
7	Greenish-gray sandy shale	877	884
6	Fine-grained greenish-gray sandstone, fossiliferous and calcareous	884	890
26	Greenish-gray shale with some interbedded fine-grained greenish-gray sandstone, somewhat calcareous	890	916
	Top of Harrisburg Run sand	916	
9	Very fine grained dark greenish-gray sandstone, fossiliferous and somewhat calcareous, with some interbedded dark greenish-gray sandy shale	916	925
8	Fine-grained light brownish-gray sandstone, fossiliferous and somewhat calcareous, with considerable interbedded dark greenish-gray shale	925	933
7	Fine-grained dark greenish-gray sandstone, fossiliferous and somewhat calcareous, with considerable interbedded dark greenish-gray shale	933	940
	Bottom of Harrisburg Run sand		940
28	Greenish to dark greenish-gray shale	940	968
7	Greenish-gray sandy shale, very fossiliferous	968	975
16	Very fine grained greenish to dark greenish-gray sandstone, somewhat calcareous, with some interbedded dark greenish-gray shale	975	991
26	Dark greenish-gray shale with a little interbedded very fine grained greenish-gray sandstone	991	1017
44	Greenish-gray shale, with some interbedded very fine grained greenish-gray sandstone in upper part	1017	1061
13	Greenish-gray sandy shale, fossiliferous	1061	1074
67	Greenish to dark greenish-gray shale, with a little interbedded very fine grained light grayish-brown sandstone, slightly calcareous	1074	1141
13	Very fine grained grayish-brown sandstone, fossiliferous and somewhat calcareous (Bradford Third)	1141	1154
77	Greenish-gray shale with a little interbedded very fine grained grayish-brown sandstone, slightly calcareous	1154	1231
	Top of Lewis Run sand	1231	
25	Fine-grained chocolate-brown sandstone, somewhat fossiliferous, with some interbedded greenish-gray shale	1231	1256
22	Dark greenish-gray shale	1256	1278
5	Very fine grained chocolate-brown sandstone, somewhat calcareous	1278	1283

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
9	Very fine grained greenish-gray sandstone, fossiliferous, with some interbedded greenish-gray sandy shale	1283	1292
	Bottom of Lewis Run sand		1292
13	Greenish-gray sandy shale, fossiliferous, with a little interbedded very fine grained chocolate-brown sandstone	1292	1305
7	Greenish-gray shale	1305	1312
13	Greenish-gray sandy shale with a little interbedded very fine grained chocolate-brown sandstone	1312	1325
24	Greenish-gray shale	1325	1349
13	Dark greenish-gray shale	1349	1362
73	Greenish-gray shale	1362	1435
28	Dark greenish-gray shale	1435	1463
17	Greenish-gray shale, with a little interbedded very fine grained greenish-gray sandstone	1463	1480
25	Dark greenish-gray shale	1480	1505
15	Greenish-gray shale, with some interbedded very fine grained grayish-brown sandstone	1505	1520
	Top of Betula sand	1520	
25	Fine-grained grayish-brown sandstone, somewhat fossiliferous, with some interbedded greenish-gray shale	1520	1545
10	Greenish-gray sandy shale, with some interbedded very fine grained grayish-brown sandstone	1545	1555
26	Dark greenish-gray shale, with some interbedded very fine grained grayish-brown sandstone	1555	1581
9	Very fine grained grayish-brown sandstone, with some interbedded greenish-gray shale	1581	1590
	Bottom of Betula sand		1590
10	Greenish-gray sandy shale, with some interbedded brownish-gray sandstone	1590	1600
16	Greenish-gray shale, with a little interbedded very fine grained brownish-gray sandstone	1600	1616
36	Greenish-gray sandy shale with some interbedded dark-gray shale	1616	1652
9	Very fine grained grayish-brown sandstone, with considerable interbedded greenish-gray shale (Haskell)	1652	1661
31	Greenish-gray shale with a little interbedded very fine grained very dark brownish-gray sandstone	1661	1692
36	Greenish-gray sandy shale with some interbedded greenish-gray shale	1692	1728
22	Dark-gray shale	1728	1750
7	Greenish-gray sandy shale with some interbedded very dark gray, almost black, shale	1750	1757
4	Gray to dark-gray shale	1757	1761
9	Gray sandy shale	1761	1770
10	Dark-gray shale	1770	1780
160	Greenish-gray shale with some interbedded greenish-gray sandy shale	1780	1940
18	Dark-gray shale with a little interbedded dark-gray sandy shale	1940	1958
16	Gray sandy shale	1958	1974
9	Greenish-gray shale	1974	1983
17	Very fine grained dark greenish-gray sandstone with some interbedded dark greenish-gray sandy shale	1983	2000
35	Greenish-gray sandy shale	2000	2035
18	Dark greenish-gray sandy shale	2035	2053
38	Greenish-gray sandy shale	2053	2091
25	Dark greenish-gray sandy shale	2091	2116
9	Very dark gray shale	2116	2125
9	Greenish-gray shale	2125	2134
10	Greenish-gray sandy shale with a little interbedded grayish-black shale	2134	2144
22	Very fine grained greenish-gray sandstone, somewhat calcareous in lower part	2144	2166
8	Dark-gray shale	2166	2174
8	Fine-grained greenish-gray sandstone, with some interbedded dark-gray shale	2174	2182
24	Greenish-gray sandy shale, with some interbedded dark-gray shale	2182	2206
14	Dark to very dark gray shale	2206	2220
16	Grayish-black shale	2220	2236
24	Very fine grained greenish-gray sandstone, with some interbedded greenish-gray sandy shale	2236	2260
	Bottom of Chemung group		2260

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
9	Greenish-gray sandy shale	2260	2269
51	Dark greenish-gray sandy shale	2269	2320
5	Gray shale	2320	2325
16	Dark greenish-gray sandy shale, with some interbedded dark-gray shale	2325	2341
69	Greenish-gray sandy shale	2341	2410
10	Very fine grained light greenish-gray sandstone with some interbedded dark greenish-gray sandy shale	2410	2420
10	Dark greenish-gray shale	2420	2430
8	Dark greenish-gray sandy shale	2430	2438
15	Dark greenish-gray shale	2438	2453
7	Very fine grained greenish-gray sandstone, slightly calcareous, with some interbedded dark-gray shale	2453	2460
20	Greenish-gray sandy shale, with a little interbedded dark gray shale	2460	2480
38	Greenish-gray sandy shale, with a little interbedded grayish-black shale	2480	2518
13	Dark greenish-gray sandy shale	2518	2531
19	Dark-gray sandy shale, with some interbedded grayish-black shale	2531	2550
26	Dark greenish-gray sandy shale	2550	2576
8	Dark greenish-gray sandy shale, with some interbedded grayish-black shale	2576	2584
28	Dark greenish-gray sandy shale	2584	2612
9	Gray to dark-gray shale	2612	2621
9	Dark greenish-gray sandy shale	2621	2630
10	Dark greenish-gray sandy shale, with some interbedded grayish-black shale	2630	2640
24	Dark greenish-gray sandy shale, with some interbedded dark-gray shale	2640	2664
21	Gray to dark-gray shale	2664	2685
15	Greenish-gray sandy shale, with a little interbedded grayish-black shale in lower part	2685	2700
36	Dark greenish-gray sandy shale, with a little interbedded dark-gray shale	2700	2736
10	Greenish-gray sandy shale	2736	2746
26	Dark greenish-gray sandy shale, with some interbedded dark-gray shale	2746	2772
7	Dark-gray shale, with some interbedded grayish-black shale	2772	2779
18	Dark greenish-gray sandy shale, with some interbedded dark-gray shale	2779	2797
11	Dark greenish-gray sandy shale, with some interbedded grayish-black shale	2797	2808
54	Greenish-gray sandy shale, with some interbedded dark-gray shale	2808	2862
23	Dark greenish-gray sandy shale, with some interbedded dark-gray shale	2862	2885
15	Very fine grained light-gray sandstone, with a little interbedded gray shale	2885	2900
46	Greenish-gray sandy shale, with some interbedded dark-gray shale	2900	2946
6	Grayish-brown sandy shale, with some interbedded gray shale	2946	2952
8	Very fine grained greenish- and brownish-gray sandstone, with some interbedded dark-gray shale	2952	2960
38	Dark-gray shale, with some interbedded dark greenish-gray sandy shale	2960	2998
20	Dark greenish-gray sandy shale	2998	3018
42	Greenish-gray sandy shale, with some interbedded gray shale	3018	3060
10	Very fine grained light greenish-gray sandstone, with some interbedded gray shale	3060	3070
8	Greenish-gray sandy shale, with some interbedded gray shale	3070	3078
7	Very fine grained greenish-gray sandstone, with some interbedded gray shale	3078	3085
20	Greenish-gray sandy shale, somewhat fossiliferous, with some interbedded gray shale	3085	3105
20	Greenish-gray sandy shale, with some interbedded dark-gray shale	3105	3125
60	Dark greenish-gray sandy shale, with some interbedded dark-gray shale	3125	3185
8	Dark-gray shale	3185	3193
12	Dark-gray sandy shale	3193	3205
28	Dark to very dark gray shale, with some interbedded dark-gray sandy shale	3205	3233

Thickness feet	Description of strata	Depth in feet Top	Bottom
7	Gray to dark-gray shale, with a little interbedded grayish-black shale	3233	3240
43	Gray to dark-gray shale	3240	3283
7	Dark Greenish-gray sandy shale	3283	3290
51	Dark to very dark gray shale	3290	3341
17	Gray shale with a little interbedded grayish-black shale	3341	3358
15	Gray shale	3358	3373
10	Grayish-black shale	3373	3383
19	Gray sandy shale, with some interbedded dark-gray shale	3383	3402
48	Gray to dark-gray shale	3402	3450
9	Greenish-gray shale, in part sandy, with some interbedded grayish-black shale	3450	3459
40	Dark-gray shale	3459	3499
24	Very fine grained dark brownish-gray sandstone with some interbedded dark-gray shale	3499	3523
44	Dark-gray shale, with a little interbedded grayish-black shale	3523	3567
59	Dark to very dark gray shale	3567	3626
12	Grayish-black shale	3626	3638
38	Dark-gray shale	3638	3676
49	Gray shale, slightly calcareous	3676	3725
31	Dark-gray shale	3725	3756
9	Dark-gray shale, with a little interbedded grayish-black shale	3756	3765
23	Dark-gray shale	3765	3788
8	Dark-gray shale, with some interbedded grayish-black shale	3788	3796
20	Dark to very dark gray shale	3796	3816
9	Gray shale, with a little interbedded grayish-black shale	3816	3825
10	Dark to very dark gray shale	3825	3835
30	Grayish-black shale, with some interbedded dark-gray shale	3835	3865
17	Very dark gray shale	3865	3882
8	Grayish-black shale	3882	3890
8	Very dark gray shale	3890	3898
28	Grayish-black shale	3898	3926
12	Dark to very dark gray shale	3926	3938
12	Grayish-black shale	3938	3950
57	Dark to very dark gray shale, with some interbedded grayish-black shale	3950	4007
66	Very dark gray shale, slightly calcareous	4007	4073
4	Very fine, dense, dark brownish-gray limestone (Genundewa)	4078	4077
	Bottom of Portage group		4077
10	Very dark gray shale, with some interbedded grayish-black shale, somewhat calcareous	4077	4087
36	Grayish-black shale, calcareous	4087	4123
36	Grayish-black shale	4123	4159
28	Grayish-black shale, somewhat calcareous	4159	4187
15	Grayish-black shale, slightly calcareous	4187	4202
	Bottom of Genesee black shale		4202
	Top of Tully limestone	4202	
8	Very fine, dense, grayish-brown limestone	4202	4210
7	Grayish-black shale, somewhat calcareous	4210	4217
3	Very fine, dense, grayish-brown limestone	4217	4220
	Bottom of Tully limestone		4220
66	Very dark gray shale, slightly calcareous	4220	4286
2	Very fine, dense, light grayish-brown limestone (Tichenor)	4286	4288
394	No samples	4288	4682
	Top of Onondaga limestone from driller's log	4678	
9	Very fine, dense, very dark brownish-gray argillaceous limestone	4682	4691
9	Very fine, crystalline, light greenish-gray to very dark brownish-gray siliceous limestone	4691	4700
5	Very fine, crystalline, light to dark brownish gray siliceous limestone	4700	4705
21	Very fine, crystalline, dark grayish-brown cherty limestone	4705	4726
	Bottom of Onondaga limestone		4726
11	Very fine, crystalline, grayish to dark grayish-brown, somewhat siliceous limestone	4726	4737
27	Very fine, crystalline, brownish to very dark brownish-gray somewhat argillaceous limestone	4737	4767

Thickness feet	Description of strata	Depth in feet Top	Bottom
19	Very fine, dense, very dark brownish-gray argillaceous limestone	4764	4783
	Bottom of Helderberg group		4783
25	Very fine, crystalline, light-gray to grayish-brown, somewhat argillaceous magnesian limestone (Cobleskill)	4783	4808
	Top of Salina group	4808	
12	Very fine, dense, light grayish-brown argillaceous magnesian limestone, with some interbedded anhydrite	4808	4820
12	Very fine, crystalline, dark brownish-gray argillaceous magnesian limestone	4820	4832
5	Very fine, crystalline, light gray anhydrite, with some associated very dark grayish-brown limestone	4832	4837
48	Very fine, dense, very dark brownish-gray argillaceous limestone, with some interbedded anhydrite	4837	4885
7	Very fine, dense, greenish-gray argillaceous limestone, with a little interbedded anhydrite	4885	4892
27	Very fine, dense, dark brownish-gray argillaceous limestone, with a little interbedded anhydrite	4892	4919
7	Dark-gray shale, somewhat calcareous, with considerable interbedded anhydrite	4919	4926
109	Very fine, dense, brown to dark-brown argillaceous and somewhat magnesian limestone, with some interbedded anhydrite	4926	5035
7	Very dark brownish-gray, almost black calcareous shale, with considerable interbedded anhydrite	5035	5042
31	Very fine, dense, brown to dark-brown argillaceous and somewhat magnesian limestone, with some interbedded anhydrite	5042	5073
22	Medium-grained, crystalline, light-gray salt	5073	5095
30	Light-gray calcareous shale, with a little interbedded anhydrite	5095	5125
	Drilling at 5125 feet on Aug. 1, 1934.		

Section No. 9

Section No. 9 was obtained in the Benjamin Haywood No. 1 well of the Atlantic Seaboard Natural Gas Company, located two-thirds of a mile west of Marvindale, Hamlin Township, McKean County, Pennsylvania. The well started 1750 feet above sea-level in the Cattaraugus formation, 263 feet above its base, according to the drillers' log, and reached the top of the Salina group. No Oriskany sandstone was encountered at this locality. The well was abandoned early in 1934.

Record of Benjamin Haywood No. 1 Well

Thickness feet	Description of strata	Depth in feet Top	Bottom
	Bottom of Cattaraugus red beds from driller's log		263
930	No samples	0	930
25	Very fine grained greenish-gray sandstone, slightly calcareous and fossiliferous, with some interbedded greenish-gray shale (Bradford First)	930	955
38	Gray shale, with some interbedded very fine grained light greenish-gray fossiliferous sandstone	955	993
82	No samples	993	1075
6	Very fine grained grayish-brown sandstone, slightly calcareous, slight show of oil at 1081	1075	1081
7	Greenish-gray sandy shale	1081	1088
12	Very fine grained, greenish-gray sandstone	1088	1100
50	No samples	1100	1150
19	Greenish-gray shale, with some interbedded very fine grained light-gray sandstone	1150	1169
63	No samples	1169	1232

Benjamin Haywood No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
19	Very fine grained light-gray shale, calcareous, fossiliferous in upper part, with a little interbedded gray shale	1232	1251
39	No samples	1251	1290
13	Dark greenish-gray sandy shale, fossiliferous	1290	1303
7	Dark-gray shale, fossiliferous	1303	1310
8	Very fine grained light greenish-gray sandstone, calcareous	1310	1318
8	Dark greenish-gray sandy shale, fossiliferous	1318	1326
36	No samples	1326	1362
8	Gray sandy shale, fossiliferous, with some interbedded very fine grained light-gray sandstone	1362	1370
30	No samples	1370	1400
20	Fine-grained light-gray sandstone, somewhat calcareous and fossiliferous, with some interbedded gray sandy shale	1400	1420
147	No samples	1420	1567
	Top of Bradford Third sand	1567	
14	Very fine grained brownish-gray sandstone, somewhat calcareous in lower part, with some interbedded gray shale	1567	1581
7	Greenish-gray shale, with some interbedded very fine grained brownish-gray sandstone, somewhat calcareous and fossiliferous	1581	1588
12	Very fine grained grayish-brown sandstone, somewhat calcareous, with considerable interbedded greenish-gray shale	1588	1600
5	Fine-grained chocolate-brown sandstone (25,000 cubic feet of gas per day, open flow)	1600	1605
6	Very fine grained chocolate-brown sandstone	1605	1611
	Bottom of Bradford Third sand		1611
24	No samples	1611	1635
	Top of Lewis Run sand	1635	
21	Very fine grained chocolate-brown sandstone, with considerable interbedded greenish-gray fossiliferous sandy shale	1635	1656
19	Gray shale, with some interbedded greenish-gray fossiliferous sandy shale	1656	1675
6	Fine grained chocolate-brown sandstone, slightly calcareous	1675	1681
	Bottom of Lewis Run Sand		1681
139	No samples	1681	1820
29	Greenish-gray shale, with a little interbedded fine-grained chocolate-brown sandstone	1820	1849
6	Greenish-gray sandy shale	1849	1855
16	Very fine grained chocolate-brown sandstone — Kane (60,000 cubic feet of gas per day, open flow)	1855	1871
49	Interbedded gray shale and sandy shale	1871	1920
	Top of Betula sand	1920	
7	Very fine grained chocolate-brown sandstone (3,000 cubic feet of gas per day, open flow)	1920	1927
12	Dark-gray sandy shale, with some interbedded very fine grained chocolate-brown sandstone	1927	1939
12	Very fine grained dark chocolate-brown sandstone, with considerable interbedded greenish-gray sandy shale	1939	1951
12	Very fine grained dark grayish-brown sandstone, with some interbedded greenish-gray sandy shale	1951	1963
	Bottom of Betula sand		1963
39	Greenish-gray shale, with some interbedded very fine grained dark grayish-brown sandstone	1963	2002
6	Very fine grained dark grayish-brown sandstone, with some interbedded greenish-gray shale (Haskell)	2002	2008
6	Greenish-gray sandy shale, with some interbedded very fine grained dark grayish-brown sandstone	2008	2014
82	Greenish-gray shale, with some interbedded very fine grained dark grayish-brown sandstone	2014	2096
72	No samples	2096	2168
6	Gray shale	2168	2174
26	Greenish-gray sandy shale	2174	2200
6	Gray shale	2200	2206
49	No samples	2206	2255

Benjamin Haywood No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
5	Dark-gray shale	2255	2260
28	Very fine grained greenish-gray sandstone, slightly calcareous, with some interbedded dark-gray shale	2260	2288
5	Gray sandy shale	2288	2293
15	Gray shale, with a little interbedded very dark gray, almost black shale	2293	2308
5	Very fine grained gray sandstone, with some interbedded gray to dark-gray shale	2308	2313
18	Greenish-gray sandy shale, with considerable interbedded chocolate-brown sandy shale	2313	2331
31	Interbedded greenish-gray sandy shale and dark-gray shale	2331	2362
246	No samples	2362	2608
12	Greenish-gray sandy shale, with some interbedded chocolate-brown sandy shale	2608	2620
10	Greenish-gray sandy shale	2620	2630
216	No samples	2630	2846
7	Chocolate-brown sandy shale	2846	2853
21	Greenish-gray sandy shale, with some interbedded dark-gray shale	2853	2874
438	No samples	2874	3312
5	Gray shale, with some interbedded grayish-black shale	3312	3317
7	Very fine grained dark greenish-gray sandstone, with some interbedded dark-gray shale	3317	3324
20	Gray to very dark gray shale	3324	3344
6	Dark greenish-gray sandy shale	3344	3350
2	Very fine grained dark greenish-gray sandstone, slightly calcareous	3350	3352
5	Dark greenish-gray sandy shale	3352	3357
8	Gray shale	3357	3365
61	No samples	3365	3426
39	Gray sandy shale	3426	3465
24	Gray shale, with some interbedded dark-gray shale	3465	3489
51	Greenish-gray sandy shale, with some interbedded dark-gray shale	3489	3540
34	Dark-gray shale, with some interbedded greenish-gray sandy shale	3540	3574
8	Gray sandy shale	3574	3582
36	Very fine grained gray sandstone, with some interbedded dark-gray shale	3582	3618
5	Dark greenish-gray sandy shale	3618	3623
10	Very fine grained gray to dark greenish-gray sandstone, with some interbedded dark-gray shale in upper part	3623	3633
6	Dark-gray sandy shale	3633	3639
37	Dark-gray shale, with some interbedded greenish-gray sandy shale	3639	3676
36	Dark greenish-gray sandy shale, with some interbedded dark-gray shale	3676	3712
31	Very fine grained dark greenish-gray sandstone, with some interbedded dark-gray shale	3712	3743
7	Very dark gray shale, with some interbedded grayish-black shale	3743	3750
35	No samples	3750	3785
43	Dark-gray shale, with a little interbedded very fine grained dark greenish-gray sandstone	3785	3828
8	Dark-gray sandy shale	3828	3836
7	Very fine grained greenish-gray sandstone	3836	3843
39	Dark-gray shale, with some interbedded dark greenish-gray sandy shale	3843	3882
18	Dark greenish-gray sandy shale, with some interbedded dark-gray shale	3882	3900
38	Gray shale, with some interbedded grayish-black shale	3900	3938
37	Dark greenish-gray sandy shale, with some interbedded dark grayish-brown sandy shale	3938	3975
25	Gray shale, with some interbedded very dark gray shale	3975	4000
13	Dark greenish-gray sandy shale, with a little interbedded dark grayish-brown sandy shale	4000	4013
25	Dark-gray shale, with some interbedded dark-gray sandy shale	4013	4038
107	No samples	4038	4145

Benjamin Haywood No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
10	Very dark gray shale, with some interbedded dark-gray sandy shale	4145	4155
27	Dark-gray shale	4155	4182
22	Gray shale	4182	4204
82	Dark to very dark gray shale, slightly calcareous	4204	4286
56	Dark-gray shale, with some interbedded grayish-black shale	4286	4342
14	Very dark gray shale	4342	4356
12	Grayish-black shale	4356	4368
16	Very dark gray shale	4368	4384
25	Grayish-black shale	4384	4409
39	Very dark gray shale	4409	4448
6	Very dark brownish-gray shale, in part calcareous	4448	4454
21	Dark-gray shale	4454	4475
30	Very dark gray shale	4475	4505
9	Very dark gray shale, somewhat calcareous	4505	4514
	Bottom of Portage group		4514
59	Grayish-black shale, somewhat calcareous	4514	4573
13	Grayish-black shale, calcareous	4573	4586
7	Grayish-black shale, somewhat calcareous	4586	4593
34	Grayish-black shale	4593	4627
12	Grayish-black shale, somewhat calcareous	4627	4639
15	Grayish-black shale	4639	4654
	Bottom of Genesee black shale		4654
4	Very fine, dense, grayish-brown limestone (Tully)	4654	4658
	Top of Hamilton group	4658	
31	Grayish-black shale, somewhat calcareous	4658	4689
12	Dark-gray shale, somewhat calcareous, with some interbedded grayish-black shale	4689	4701
7	Grayish-black shale	4701	4708
6	Very dark gray shale, somewhat calcareous	4708	4714
6	Grayish-black shale, somewhat calcareous	4714	4720
5	Dark-gray shale, somewhat calcareous	4720	4725
16	Grayish-black shale, somewhat calcareous	4725	4741
11	Very dark gray shale, somewhat calcareous	4741	4752
18	Dark-gray shale, somewhat calcareous	4752	4770
22	Dark to very dark gray shale, calcareous	4770	4792
10	Very dark gray shale, somewhat calcareous	4792	4802
38	Dark-gray shale, somewhat calcareous	4802	4840
6	Dark-gray shale, calcareous	4840	4846
39	Dark-gray shale, somewhat calcareous	4846	4885
7	Grayish-black shale, somewhat calcareous	4885	4892
38	Very dark gray shale, somewhat calcareous	4892	4930
12	Grayish-black shale, somewhat calcareous	4930	4942
18	Very dark gray shale, calcareous	4942	4960
65	Black shale	4960	5025
54	Black shale, slightly calcareous	5025	5079
35	Black shale, with abundant minute pyrite crystals	5079	5114
9	Black shale, calcareous	5114	5123
	Top of Onondaga limestone	5123	
27	Very fine, crystalline, dark-gray limestone, cherty in lower part	5123	5150
17	Very fine, crystalline, light-gray cherty limestone	5150	5167
6	Very fine, crystalline, brownish-gray cherty limestone, fossiliferous	5167	5173
9	Very fine, crystalline, dark brownish-gray cherty limestone, fossiliferous	5173	5182
	Bottom of Onondaga limestone		5182
	No Oriskany sandstone present		
	Top of Helderberg group	5182	
8	Very fine, crystalline, very dark brownish-gray limestone	5182	5190
8	Very fine, dense, very dark brownish-gray argillaceous limestone	5190	5198
20	Very fine, crystalline, dark brownish-gray limestone	5198	5218
8	Very fine, crystalline, light to very dark brownish-gray limestone, somewhat magnesian	5218	5226
4	Very fine, dense, brownish-gray limestone, somewhat cherty and magnesian	5226	5230
12	Very fine, dense, very dark brownish-gray limestone	5230	5242
27	Very fine, crystalline, light brownish-gray magnesian limestone (Cobleskill)	5242	5269
	Total depth		5269

Section No. 10

Section No. 10 was obtained in well No. 3737 of the United Natural Gas Company, also commonly referred to as the Kane deep well, located 4 miles south of Kane and 8,000 feet S. 55° W. from Lamont Station on Warrant 3788, Highland Township, Elk County, Pennsylvania at an elevation of 1836 feet above sea-level. Drilling was started in 1926 and completed in 1928. No commercial production of oil or gas was encountered below the Kane sand. The following record is based upon the study made of a complete set of samples of the cuttings.

Record of Well No. 3737 of the United Natural Gas Company

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
38	Medium- to coarse-grained sandstone, contains rounded quartz pebbles up to 65 mm. in diameter	0	38
42	Medium- to coarse-grained light greenish-gray sandstone, contains discoidal quartz pebbles up to 127 mm. in diameter	38	80
10	Greenish-gray shale, fossiliferous	80	90
5	Medium-grained light-gray sandstone, with occasional quartz grains up to 2.5 mm. in diameter, calcareous	90	95
10	Greenish-gray shale, fossiliferous	95	105
95	Medium grained, light-gray sandstone, with occasional quartz grains up to 2.5 mm. in diameter, sparingly fossiliferous and in part calcareous	105	200
	Bottom of Knapp formation		200
30	Greenish-gray shale	200	230
5	Greenish-gray sandy shale	230	235
55	Fine-grained light greenish-gray sandstone, sparingly fossiliferous and somewhat calcareous in lower part	235	290
10	Greenish-gray sandy shale, slightly calcareous	290	300
40	Fine- to medium-grained light greenish-gray sandstone, slightly calcareous, contains carbonized plant remains	300	340
15	Greenish-gray to grayish-brown sandy shale	340	355
15	Fine-grained light greenish-gray sandstone, in part calcareous	355	370
	Bottom of Oswayo formation		370
35	Very fine-grained brick-red to reddish-brown argillaceous sandstone	370	405
10	Reddish-brown shale	405	415
10	Very fine-grained reddish-brown argillaceous sandstone	415	425
12	Brick-red shale	425	437
37	Reddish-brown sandy shale	437	474
18	Greenish-gray shale and sandy shale	474	492
24	Brick-red to reddish brown sandy shale	492	516
18	Very fine-grained reddish-brown argillaceous sandstone	516	534
18	Greenish-gray sandy shale, contains carbonized plant stems	534	552
6	Very fine-grained reddish-brown argillaceous sandstone	552	558
6	Reddish-brown shale	558	564
30	Greenish-gray sandy shale	564	594
6	Reddish-brown sandy shale	594	600
12	Very fine-grained dark grayish-brown to greenish-gray sandstone, somewhat calcareous	600	612
27	Very fine-grained reddish-brown argillaceous sandstone	612	639
14	Greenish-gray shale	639	653
7	Very fine-grained brick-red argillaceous sandstone	653	660
11	Reddish-brown shale	660	671
12	Brick-red sandy shale	671	683
6	Very fine-grained brick-red argillaceous sandstone	683	689
8	Reddish-brown sandy shale	689	697
	Bottom of Cattaraugus formation		697

Well No. 3737 of the United Natural Gas Company (cont.)

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
115	Greenish-gray sandy shale, fossiliferous	697	812
12	Very fine-grained dark grayish-brown to greenish-gray sandstone, very fossiliferous	812	824
36	Greenish-gray sandy shale, fossiliferous	824	860
12	Greenish-gray shale	860	872
72	Greenish-gray sandy shale, with some interbedded thin layers of very fine-grained light greenish-gray sandstone, fossiliferous	872	944
54	Greenish-gray shale, with some interbedded thin layers of very fine-grained greenish-gray sandstone, fossiliferous	944	998
30	Greenish-gray sandy shale, with some interbedded very fine-grained light greenish-gray sandstone, fossiliferous	998	1028
12	Greenish-gray shale, with some interbedded very fine-grained light brownish-gray sandstone, fossiliferous	1028	1040
6	Very fine-grained light brownish- and greenish-gray sandstone, slightly calcareous	1040	1046
24	Dark purplish-gray sandy shale, with some interbedded greenish-gray sandy shale	1046	1070
6	Greenish-gray shale	1070	1076
6	Purplish-gray sandy shale	1076	1082
48	Purplish-gray shale, with a few interbedded thin layers of very fine grained greenish-gray sandstone, fossiliferous	1082	1130
6	Greenish-gray sandy shale	1130	1136
6	Purplish-gray sandy shale	1136	1142
18	Fine-grained light greenish-gray sandstone, fossiliferous and slightly calcareous	1142	1160
60	Greenish-gray sandy shale, with some interbedded thin layers of very fine-grained light greenish-gray sandstone, slightly calcareous	1160	1220
24	Greenish-gray shale	1220	1244
6	Very fine-grained light greenish-gray sandstone, fossiliferous and somewhat calcareous	1244	1250
48	Greenish-gray shale, with some interbedded thin layers of very fine-grained light-greenish-gray sandstone, which are somewhat fossiliferous and calcareous	1250	1298
24	Greenish-gray sandy shale	1298	1322
53	Greenish-gray shale, with some interbedded thin layers of very fine-grained light greenish-gray sandstone, which are fossiliferous and somewhat calcareous	1322	1375
10	Greenish-gray sandy shale, with some interbedded thin layers of very fine-grained light greenish-gray sandstone, which are fossiliferous and somewhat calcareous	1375	1385
	Top of Glade sand	1385	
5	Fine-grained light greenish-gray sandstone, somewhat calcareous	1385	1390
5	Greenish-gray shale	1390	1395
5	Fine-grained light greenish-gray sandstone	1395	1400
6	Greenish-gray shale	1400	1406
6	Very fine-grained greenish-gray sandstone	1406	1412
24	Greenish-gray shale	1412	1436
6	Very fine-grained greenish-gray sandstone	1436	1442
	Bottom of Glade sand		1442
41	Greenish-gray shale, with some interbedded fine to coarse-grained light-gray sandstone	1442	1483
10	Fine-grained light gray sandstone, with occasional quartz grains up to 3 mm. in diameter (Clarendon sand)	1483	1493
57	Greenish-gray shale	1493	1550
20	Fine-grained light greenish-gray sandstone (Cherry Grove, Gartland sand)	1550	1570
112	Greenish-gray shale	1570	1682
68	Greenish-gray shale, with some interbedded thin layers of fine-grained light greenish-gray sandstone, in part fossiliferous	1682	1750
5	Fine-grained light-gray sandstone	1750	1755
105	Greenish-gray shale	1755	1860
88	Greenish-gray shale, with some interbedded thin layers of fine-grained light greenish-gray sandstone and greenish-gray sandy shale; fossils	1860	1948

Well No. 3737 of the United Natural Gas Company (cont.)

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
22	Greenish-gray shale, with some interbedded thin layers of fine-grained grayish-brown sandstone (horizon of Bradford Third sand)	1948	1970
36	Greenish-gray shale	1970	2006
12	Greenish-gray sandy shale	2006	2018
52	Greenish-gray shale, with some interbedded sandy shale	2018	2070
74	Greenish-gray shale, with some interbedded thin layers of fine-grained grayish-brown sandstone, fossiliferous	2070	2144
10	Gray shale, fossiliferous	2144	2154
5	Greenish-gray sandy shale	2154	2159
36	Fine-grained grayish-brown sandstone, fossiliferous (Kane sand)	2159	2195
60	Greenish-gray sandy shale, with some interbedded thin layers of fine-grained grayish-brown sandstone, sparingly fossiliferous	2195	2255
10	Very fine-grained grayish-brown sandstone, with considerable interbedded greenish-gray sandy shale (Betula)	2255	2265
10	Greenish-gray shale, sparingly fossiliferous	2265	2275
73	Greenish-gray sandy shale	2275	2348
34	Greenish-gray shale	2348	2382
60	Greenish-gray sandy shale	2382	2442
43	Greenish-gray to gray shale	2442	2485
12	Dark-gray sandy shale, fossiliferous	2485	2497
113	Greenish-gray shale	2497	2610
32	Greenish-gray shale, with some interbedded thin layers of very fine grained grayish-brown sandstone	2610	2642
134	Gray and greenish-gray shale	2642	2776
219	Gray and greenish-gray shale, with interbedded thin seams of grayish-black shale, and very fine grained light greenish-gray sandstone	2776	2995
10	Greenish-gray sandy shale	2995	3005
	Bottom of Chemung group		3005
223	Gray and greenish-gray shale, with some interbedded greenish-gray sandy shale and a few thin seams of grayish-black shale	3005	3228
	Bottom of Wiscoy shale		3228
40	Very fine grained light greenish-gray sandstone, slightly calcareous, contains fragments of plant remains in the upper part	3228	3268
25	Greenish-gray sandy shale	3268	3293
13	Very fine grained light greenish-gray sandstone	3293	3306
6	Greenish-gray sandy shale	3306	3312
6	Very fine grained light greenish-gray sandstone	3312	3318
24	Greenish-gray sandy shale	3318	3342
18	Very fine grained light greenish-gray sandstone, slightly calcareous	3342	3360
18	Greenish-gray shale	3360	3378
12	Very fine grained light greenish-gray sandstone, somewhat calcareous	3378	3390
	Bottom of Nunda sandstone		3390
90	Gray and greenish-gray shale, with some interbedded thin layers of very fine grained light greenish-gray sandstone, slightly calcareous	3390	3480
152	Gray and greenish-gray shale, with some interbedded greenish-gray sandy shale	3480	3632
24	Greenish-gray sandy shale	3632	3656
	Bottom of Gardeau flags and shale		3656
6	Very fine grained dark grayish-brown sandstone (Grimes)	3656	3662
256	Gray and greenish-gray shale, with a little interbedded greenish-gray sandy shale and very fine grained light greenish-gray sandstone	3662	3918
12	Very fine grained dark grayish-brown sandstone	3918	3930
36	Gray and greenish-gray shale	3930	3966
6	Very fine grained dark grayish-brown sandstone	3966	3972
23	Gray to dark-gray shale	3972	3995
20	Very fine grained dark grayish-brown sandstone	3995	4015
45	Gray to dark-gray shale	4015	4060
	Bottom of Hatch flags and shale		4060
42	Grayish-black shale	4060	4102
18	Dark-gray shale	4102	4120
18	Grayish-black shale	4120	4138

Well No. 3737 of the United Natural Gas Company (cont.)

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
46	Dark-gray shale, with some interbedded grayish-black shale	4138	4184
5	Grayish-black shale	4184	4189
	Bottom of Rhinestreet black shale		4189
10	Dark-gray shale	4189	4199
33	Gray shale, with some interbedded very fine grained dark grayish-brown sandstone	4199	4232
12	Brownish-gray shale	4232	4244
6	Greenish-gray shale	4244	4250
12	Grayish to brownish-black shale	4250	4262
6	Brownish-gray shale	4262	4268
6	Greenish-gray shale	4268	4274
13	Grayish to brownish-black shale	4274	4287
13	Dark-gray shale	4287	4300
12	Grayish-black shale	4300	4312
30	Gray shale	4312	4342
12	Brownish-black shale	4342	4354
18	Brownish-gray shale	4354	4372
6	Grayish-black shale	4372	4378
6	Dark-gray shale	4378	4384
6	Grayish-black shale	4384	4390
48	Dark-gray shale	4390	4438
6	Grayish-black shale	4438	4444
34	Very dark gray shale	4444	4478
6	Grayish-black shale	4478	4484
12	Greenish-gray shale	4484	4496
88	Dark-gray shale	4496	4584
	Bottom of Cashaqua shale		4584
18	Grayish-black shale	4584	4602
6	Very dark gray shale	4602	4608
8	Grayish-black shale	4608	4616
12	Dark-gray shale	4616	4628
6	Grayish-black shale	4628	4634
24	Very dark gray shale	4634	4658
12	Grayish-black shale	4658	4670
30	Dark-gray shale	4670	4700
6	Grayish-black shale	4700	4706
	Bottom of Middlesex black shale		4706
31	Very dark gray shale	4706	4737
36	Very dark gray sandy shale	4737	4773
	Bottom of West River shale		4773
	Bottom of Portage group		4773
30	Grayish-black shale, somewhat calcareous	4773	4803
6	Very dark gray sandy shale, calcareous	4803	4809
63	Grayish-black shale, somewhat calcareous	4809	4872
	Bottom of Genesee black shale		4872
6	Very fine, crystaliine, dark brownish-gray limestone (Tully)	4872	4878
	Top of Hamilton group	4878	
6	Grayish-black shale, slightly calcareous	4878	4884
6	Very dark gray shale, slightly calcareous	4884	4890
6	Grayish-black shale, slightly calcareous	4890	4896
59	Dark to very dark gray shale, slightly calcareous	4896	4955
6	Grayish-black shale, calcareous	4955	4961
18	Very dark gray shale, somewhat calcareous	4961	4979
11	Gray shale, slightly calcareous	4979	4990
90	Dark-gray shale, somewhat calcareous	4990	5080
24	Very dark-gray shale, slightly calcareous	5080	5104
12	Grayish-black shale	5104	5116
36	Very dark gray shale, somewhat calcareous	5116	5152
6	Black shale, calcareous	5152	5158
9	Grayish-black shale, somewhat calcareous	5158	5167
107	Black shale, with a thin seam of dense light-gray limestone at 5208 feet	5167	5274
22	Black shale, calcareous, with a thin seam of dense, nearly black, argillaceous limestone near base	5274	5296
10	Dark brownish-gray shale, very calcareous	5296	5306
6	Grayish-black shale	5306	5312
4	Very fine, crystalline, dark-gray limestone	5312	5316
2	Black shale	5316	5318
	Bottom of Hamilton group		5318
82	Very fine, crystalline, light-gray to dark brownish-gray cherty limestone (Onondaga)	5318	5400
20	Very fine, crystalline, gray to dark-gray limestone (Helderberg)	5400	5420

Well No. 3737 of the United Natural Gas Company (cont.)

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
28	Very fine, crystalline, brownish-gray siliceous magnesian limestone, somewhat cherty (Cobleskill)	5420	5448
	Top of Salina group	5448	
50	Very fine, crystalline, brownish-gray siliceous limestone, somewhat cherty; a little salt water at 5476 feet	5448	5498
6	Very fine, crystalline, grayish-brown to dark-gray siliceous magnesian limestone; somewhat cherty	5498	5504
24	Very fine, crystalline, dark brownish-gray siliceous limestone; somewhat cherty	5504	5528
32	Very fine, crystalline, light-gray to dark brownish-gray siliceous magnesian limestone	5528	5560
12	Very fine, crystalline, light to dark grayish-brown siliceous limestone; somewhat cherty	5560	5572
6	Very fine, crystalline, light to dark grayish-brown siliceous magnesian limestone	5572	5578
24	Very fine, dense, gray argillaceous limestone	5578	5602
54	Very fine, dense, grayish-brown argillaceous and siliceous magnesian limestone	5602	5656
12	Very fine, dense, grayish-brown argillaceous limestone	5656	5668
37	Very fine, dense, light to dark grayish-brown argillaceous limestone	5668	5705
5	Very fine, crystalline, brownish-gray magnesian limestone, with much associated anhydrite	5705	5710
24	Very dark gray dolomitic shale	5710	5734
12	Coarse, crystalline salt	5734	5746
12	Dark gray, slightly calcareous, shale	5746	5758
12	Medium- to coarse-crystalline salt	5758	5770
5	Dark-gray shale	5770	5775
13	Medium-crystalline salt	5775	5788
6	Dark-gray, slightly calcareous shale	5788	5794
7	Medium-crystalline salt	5794	5801
48	Very fine, dense, light-gray argillaceous limestone	5801	5849
54	Interbedded very fine, dense, light-gray argillaceous limestone and dark brownish-gray magnesian limestone	5849	5903
7	Medium-crystalline salt	5903	5910
18	Very fine, dense, light to dark grayish-brown argillaceous magnesian limestone	5910	5928
18	Very fine, dense, brown to dark grayish-brown argillaceous limestone	5928	5946
24	Very fine, dense, light to dark grayish-brown argillaceous magnesian limestone	5946	5970
18	Very fine, dense, light to dark grayish-brown argillaceous limestone, with a little anhydrite	5970	5988
6	Very fine, dense, grayish-brown argillaceous magnesian limestone	5988	5994
16	Medium- to coarse-crystalline salt	5994	6010
5	Very fine, dense, grayish-brown argillaceous limestone	6010	6015
30	Coarse, crystalline salt	6015	6045
5	Very fine, dense, grayish-brown argillaceous limestone	6045	6050
5	Coarse-crystalline salt	6050	6055
5	Very fine, dense, grayish-brown argillaceous limestone	6055	6060
15	Gray to dark gray shale	6060	6075
10	Very fine, dense, grayish-brown argillaceous limestone	6075	6085
10	Gray shale	6085	6095
5	Very fine, dense, dark brownish-gray argillaceous limestone	6095	6100
270	Light gray to gray clay and shale, somewhat calcareous	6100	6370
15	Very fine, dense, dark brownish-gray argillaceous magnesian limestone	6370	6385
35	Brownish-gray clay, somewhat calcareous	6385	6420
25	Very fine, dense, dark brownish-gray argillaceous magnesian limestone	6420	6445
5	Medium-crystalline salt	6445	6450
5	Very fine, dense, dark grayish-brown argillaceous limestone	6450	6455
25	Dark brownish-gray shale, somewhat calcareous	6455	6480
5	Medium-crystalline salt	6480	6485

Well No. 3737 of the United Natural Gas Company (cont.)

Thickness feet	Description of strata	Depth in feet Top	Bottom
5	Light gray clay	6485	6490
15	Dark brownish-gray to brownish-black shale, slightly calcareous	6490	6505
20	Very fine, dense, dark brownish-gray argillaceous magnesian limestone	6505	6525
55	Dark-gray shale, somewhat calcareous	6525	6580
	Bottom of Salina group		6580
240	Very fine, crystalline, brownish-gray to very dark grayish-brown argillaceous magnesian limestone and dolomite	6580	6820
45	Very fine, crystalline, dark grayish-brown sandy magnesian limestone	6820	6865
35	Very fine, crystalline, dark brownish-gray siliceous magnesian limestone	6865	6900
	Bottom of Lockport dolomite		6900
24	Dark brownish-gray shale, slightly dolomitic	6900	6924
16	Very fine, crystalline, dark brownish-gray argillaceous magnesian limestone	6924	6940
15	Dark brownish-gray shale, somewhat dolomitic	6940	6955
13	Very fine, crystalline, dark brownish-gray argillaceous magnesian limestone	6955	6968
10	Greenish-gray shale	6968	6978
14	Grayish-purple shale, with some interbedded greenish-gray shale	6978	6992
29	Greenish-gray shale, with some interbedded grayish-purple shale	6992	7021
25	Grayish-green shale, with a few interbedded thin layers of very fine, crystalline, light-gray limestone	7021	7046
24	Grayish-purple shale, with some interbedded greenish-gray shale	7046	7070
4	Very fine, crystalline, gray magnesian limestone (Reynales)	7070	7074
2	Greenish-gray shale	7074	7076
	Bottom of Clinton group, top of Medina group		7076
4	Reddish-brown sandy shale	7076	7080
15	Very fine grained reddish-brown sandstone	7080	7095
12	Very fine grained red and pink sandstone	7095	7107
1	Dark brownish-red shale	7107	7108
5	Very fine grained red and pink sandstone	7108	7113
7	Reddish-brown sandy shale	7113	7120
6	Very fine grained light-pink and gray sandstone	7120	7126
10	Interbedded reddish-brown and greenish-gray sandy shale	7126	7136
7	Very fine grained light-pink and greenish-gray sandstone	7136	7143
3	Reddish-brown sandy shale	7143	7146
	Bottom of Red Medina or Grimsby		7146
5	Very fine grained light greenish-gray sandstone	7146	7151
2	Dark greenish-gray sandy shale	7151	7153
8	Very fine grained light-gray sandstone	7153	7161
1	Dark-gray shale	7161	7162
1	Very fine grained light greenish-gray sandstone	7162	7163
4	Greenish-gray sandy shale	7163	7167
1	Very fine grained light greenish-gray sandstone	7167	7168
2	Greenish-gray shale	7168	7170
4	Very fine grained light greenish-gray shale	7170	7174
1	Greenish-gray shale	7174	7175
67	Very fine grained light-gray sandstone	7175	7242
	Bottom of White Medina or Whirlpool		7242
	Top of Queenston red shale	7242	
303	Reddish-brown sandy shale	7242	7545
277	Reddish-brown sandy shale, somewhat calcareous	7545	7822
108	Reddish-brown sandy shale	7822	7930
	Well stopped in Queenston shale at a total depth of		7930

The first black shales observed in the cuttings occur in a zone of gray and greenish-gray shale extending from 2776 to 2995 feet. This zone, which is characterized by fairly numerous thin seams of interbedded grayish-black shale, it is believed, occupies the stratigraphic position of the Dunkirk black shale of the Lake Erie section. The underlying ten feet of greenish-gray sandy shale probably represent the horizon of the Long Beards Riffs sandstone of the Genesee Valley section.[85] Similar thin beds of black shale occur at this horizon in the Genesee Valley region.

Section No. 11

Section No. 11 was obtained in a well completed by the Potter Development Company during August, 1932 on the A. Matteson farm in the southwestern corner of Hebron Township, Potter County, Pa., 5 miles northeast of Roulette. The well is along the axis of the Hebron anticline, southwest of the recently discovered Hebron gas pool, at an elevation of 2180 feet. An examination of the outcrops along the hillside below the well showed that drilling started in the Cattaraugus red beds, 56 feet above their base. No commercial production of gas or oil was encountered. A complete set of samples of the cuttings from this well, starting at 630 feet, was available for the preparation of Section No. 11.

Record of A. Matteson No. 1 Well

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
	Top of Chemung group	56	
630	No samples collected	0	630
2	Greenish-gray sandy shale	630	632
	Top of Bradford First sand (Cuba)	632	
27	Very fine grained light greenish-gray sandstone, slightly calcareous	632	659
16	Greenish-gray shale	659	675
23	Very fine grained greenish-gray sandstone, slightly calcareous	675	698
	Bottom of Bradford First sand		698
10	Dark greenish-gray sandy shale	698	708
22	Gray shale	708	730
6	Fine grained light greenish-gray sandstone, slightly calcareous	730	736
94	Gray shale, with a little interbedded dark greenish-gray fossiliferous sandy shale	736	830
6	Very fine grained light-gray sandstone, somewhat calcareous and very fossiliferous	830	836
12	Gray shale, fossiliferous	836	848
7	Very fine grained light brownish-gray sandstone, somewhat calcareous and fossiliferous	848	855
8	Greenish-gray shale	855	863
29	Fine-grained light brownish-gray sandstone, somewhat calcareous and fossiliferous	863	892
29	Greenish-gray shale	892	921
39	Greenish-gray sandy shale, somewhat calcareous and very fossiliferous	921	960
135	Gray to dark-gray shale, with a little interbedded fine-grained light greenish-gray fossiliferous sandstone	960	1095
15	Greenish-gray sandy shale, fossiliferous	1095	1110
2	Fine-grained dark grayish-brown sandstone, somewhat calcareous and fossiliferous	1110	1112
24	Greenish-gray shale	1112	1136
18	Fine-grained light grayish-brown sandstone, slightly calcareous and fossiliferous, with some interbedded greenish-gray shale	1136	1154
88	Greenish-gray shale, in part fossiliferous	1154	1242
48	Dark gray shale	1242	1290
24	Fine-grained chocolate-brown sandstone, with considerable interbedded greenish-gray shale (Crandall Hill or Bradford Third)	1290	1314
16	Greenish-gray shale, with some interbedded fine-grained chocolate-brown sandstone	1314	1330
176	Greenish-gray shale	1330	1506
19	Very fine grained, light grayish-brown sandstone, with some interbedded greenish-gray shale	1506	1525
9	Gray shale	1525	1534
6	Very fine grained chocolate-brown sandstone, slightly calcareous	1534	1540

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[85] John M. Clarke and D. Dana Luther, Geologic map and description of the Portage and Nunda Quadrangles; New York State Mus. Bull. 118, p. 65, 1908.

A. Matteson No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
8	Greenish-gray shale	1540	1548
8	Dark-gray sandy shale	1548	1556
6	Very fine grained dark chocolate-brown sandstone	1556	1562
54	Dark-gray sandy shale, with a little interbedded gray shale	1562	1616
74	Dark-gray shale, with some interbedded greenish-gray sandy shale	1616	1690
8	Very fine grained grayish-brown sandstone	1690	1698
114	Greenish-gray sandy shale	1698	1812
78	Dark-gray sandy shale	1812	1890
66	Dark-gray shale	1890	1956
6	Grayish-black shale	1956	1962
11	Very dark gray shale	1962	1973
122	Dark greenish-gray sandy shale	1973	2095
6	Very fine grained light-gray sandstone, slightly calcareous	2095	2101
7	Dark grayish-brown sandy shale	2101	2108
32	Dark-gray sandy shale	2108	2140
22	Dark-gray shale	2140	2162
7	Dark grayish-brown sandy shale	2162	2169
31	Dark-gray shale	2169	2200
22	Very dark gray shale	2200	2222
10	Grayish-black shale	2222	2232
8	Very fine grained grayish-brown sandstone	2232	2240
7	Very dark gray shale	2240	2247
4	Grayish-brown sandy shale	2247	2251
19	Greenish-gray sandy shale	2251	2270
10	Brownish-gray sandy shale	2270	2280
70	Dark greenish-gray sandy shale	2280	2350
29	Very dark grayish-brown sandy shale	2350	2379
10	Gray shale	2379	2389
19	Very fine grained dark grayish-brown sandstone	2389	2408
10	Dark grayish-brown sandy shale	2408	2418
28	Very fine grained dark grayish-brown sandstone, slightly calcareous	2418	2446
64	Dark greenish-gray sandy shale	2446	2510
18	Very fine grained dark grayish-brown sandstone	2510	2528
17	Greenish-gray sandy shale	2528	2545
8	Very fine grained greenish-gray sandstone, slightly calcareous	2545	2553
	Bottom of Chemung group		2553
51	Dark greenish-gray sandy shale	2553	2604
2	Grayish-black shale	2604	2606
8	Very dark grayish-brown sandy shale, containing plant fragments	2606	2614
51	Gray to dark-gray sandy shale	2614	2665
10	Grayish-black shale	2665	2675
33	Dark-gray shale	2675	2708
10	Very dark gray shale	2708	2718
18	Greenish-gray sandy shale	2718	2736
16	Dark grayish-brown sandy shale	2736	2752
22	Dark-gray sandy shale	2752	2774
10	Very fine grained very dark brownish-gray sandstone	2774	2784
206	Dark-gray sandy shale	2784	2990
17	Dark grayish-brown sandy shale	2990	3007
48	Dark gray shale, with some interbedded greenish-gray sandy shale	3007	3055
6	Very fine grained greenish-gray sandstone	3055	3061
20	Very fine grained dark brownish-gray sandstone	3061	3081
10	Greenish-gray to dark-gray shale	3081	3091
8	Very fine grained, very dark brownish-gray sandstone	3091	3099
40	Gray to dark-gray shale	3099	3139
43	Dark-gray sandy shale, with some interbedded dark gray shale	3139	3182
7	Very fine grained dark greenish-gray and grayish-brown sandstone, slightly calcareous	3182	3189
76	Dark-gray sandy shale	3189	3265
80	Dark-gray shale	3265	3345
18	Dark-gray sandy shale	3345	3363
35	Dark-gray shale	3363	3398
10	Grayish-black shale	3398	3408
93	Dark greenish-gray sandy shale, with some interbedded dark-gray shale	3408	3501
12	Dark-gray shale	3501	3513

A. Matteson No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
5	Very fine grained dark greenish and brownish-gray sandstone	3513	3518
10	Dark-gray shale	3518	3528
18	Very fine grained very dark greenish-gray sandstone, with some interbedded very dark gray shale	3528	3546
19	Very fine grained dark greenish and brownish-gray sandstone	3546	3565
56	Dark to very dark gray shale	3565	3621
19	Very fine grained dark greenish-gray sandstone, with some interbedded dark-gray shale	3621	3640
178	Dark to very dark gray shale	3640	3818
27	Grayish-black shale	3818	3845
180	Dark to very dark gray shale	3845	4025
9	Grayish-black shale	4025	4034
11	Dark-gray shale	4034	4045
50	Grayish-black shale, with some interbedded dark-gray shale	4045	4095
8	Very dark gray shale	4095	4103
22	Black shale	4103	4125
95	Grayish-black shale, with some interbedded dark-gray shale	4125	4220
55	Very dark gray shale	4220	4275
70	Very dark gray shale, slightly calcareous	4275	4345
22	Grayish-black shale, slightly calcareous	4345	4367
1	Very fine, dense, very dark brownish-gray fossiliferous limestone (Genundewa)	4367	4368
	Bottom of Portage group		4368
42	Grayish-black shale, somewhat calcareous	4368	4410
25	Grayish-black shale, slightly calcareous	4410	4435
71	Grayish-black shale	4435	4506
61	Grayish-black shale, slightly calcareous	4506	4567
	Bottom of Genesee black shale		4567
18	Very fine, dense, dark brownish-gray argillaceous limestone, with some interbedded grayish-black calcareous shale	4567	4585
30	Very fine, dense, dark brownish-gray argillaceous limestone	4585	4615
	Bottom of Tully limestone		4615
10	Very dark gray shale, somewhat calcareous	4615	4625
25	Grayish-black shale, slightly calcareous	4625	4650
6	Very dark gray shale	4650	4656
20	Grayish-black shale	4656	4676
9	Grayish-black shale, somewhat calcareous	4676	4685
10	Very dark gray shale, somewhat calcareous	4685	4695
10	Very dark gray shale	4695	4705
30	Grayish-black shale, slightly calcareous	4705	4735
34	Very dark gray shale, somewhat calcareous	4735	4769
41	Very dark gray shale, slightly calcareous	4769	4810
7	Grayish-black shale, slightly calcareous	4810	4817
13	Very dark gray shale	4817	4830
5	Grayish-black shale	4830	4835
25	Very dark gray shale, slightly calcareous	4835	4860
10	Grayish-black shale, slightly calcareous	4860	4870
75	Very dark gray shale, slightly calcareous	4870	4945
20	Grayish-black shale, somewhat calcareous	4945	4965
19	Very dark gray shale, slightly calcareous	4965	4984
8	Very dark gray shale, calcareous	4984	4992
8	Grayish-black shale, calcareous	4992	5000
35	Very dark gray shale, calcareous	5000	5035
18	Grayish-black shale, calcareous	5035	5053
48	Black shale, somewhat calcareous	5053	5101
46	Black shale, slightly calcareous	5101	5147
	Bottom of Hamilton group		5147
12	Very fine, crystalline, light to dark-gray limestone	5147	5159
15	Very fine, dense, brownish-gray cherty limestone	5159	5174
	Bottom of Onondaga limestone		5174
5	Very fine, crystalline, dark brownish-gray cherty limestone, with occasional well-rounded fine to medium-sized quartz grains	5174	5179
	Bottom of Oriskany horizon		5179
66	Very fine, crystalline, very dark brownish-gray siliceous limestone	5179	5245
	Bottom of Helderberg limestone		5245
5	Very fine, dense, very dark gray limestone (Cobleskill)	5245	5250
	Top of Salina group	5250	

A. Matteson No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
24	Very fine, dense, gray argillaceous and siliceous dolomitic limestone	5250	5274
38	Very fine, dense, very dark brownish-gray argillaceous and siliceous dolomitic limestone	5274	5312
	Bottom of Bertie water lime		5312
88	Very fine, dense, very dark brownish-gray argillaceous dolomitic limestone containing some anhydrite	5312	5400
7	Gray calcareous shale, containing a little anhydrite	5400	5407
35	Very fine, dense, dark brownish-gray argillaceous dolomitic limestone	5407	5442
5	Dark gray shale, somewhat calcareous	5442	5447
81	Very fine, dense, dark brownish-gray argillaceous dolomitic limestone containing some anhydrite	5447	5528
5	Medium-grained, crystalline, light gray salt	5528	5533
7	Very fine, dense, dark brownish-gray argillaceous dolomitic limestone	5533	5540
10	Medium-grained, crystalline, light gray salt	5540	5550
	Well stopped in Camillus formation at a total depth of		5550

Section No. 12

In September, 1928, the Belmont Quadrangle Drilling Corporation encountered an open flow of 3,500,000 cubic feet of gas per day in the upper part of the Tully limestone in a well on the Gilbert farm, two miles north of Richburg, in the Town of Wirt, Allegany County, New York. The well started 60 feet below the Wolf Creek horizon, the base of the Cattaraugus formation[86] at an elevation of 2072 feet above sea-level. It was later continued to the Queenston red shale, but no additional gas or oil was discovered. Shortly thereafter, T. H. Sawyer and the Belmont Quadrangle Drilling Corporation, jointly, drilled another well into the salt beds of the Salina group, half a mile northwest of Richburg, starting at an elevation of 1860 feet. No commercial production of gas or oil was obtained below the Richburg sand in this well.

A complete set of samples of the cuttings from the Gilbert well from a depth of 255 feet to 4008 feet was obtained through the courtesy of the operators and a similar set from 3782 feet to 4847 feet from the Sawyer well. Section No. 12 has been compiled from the information furnished by these samples and the drillers' log of the Gilbert well below the 4008-foot level.

Record of Gilbert No. 1 Well

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
	Top of Chemung (approximate)	0	
255	No samples collected	0	255
5	Very fine grained dark brownish-gray sandstone	255	260
94	No samples collected	260	354
14	Greenish-gray sandy shale, with some interbedded very fine grained dark brownish-gray sandstone	354	368
8	Fine-grained very dark reddish-brown sandstone, fossiliferous	368	376
9	Greenish-gray sandy shale	376	385
10	Fine-grained very light greenish-gray sandstone	385	395
5	Fine-grained dark reddish-brown sandstone, somewhat calcareous	395	400
2	Fine-grained very light greenish-gray sandstone	400	402
6	Greenish-gray shale	402	408

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[86] George H. Chadwick, Oral communication, December 27, 1934.

Gilbert No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
137	No samples collected	408	545
	Top of Bradford First sand (Cuba)	545	
55	Fine-grained nearly white sandstone, somewhat calcareous	545	600
15	Greenish-gray sandy shale	600	615
5	Fine-grained very light greenish-gray sandstone, somewhat calcareous	615	620
10	Greenish-gray shale	620	630
10	Fine-grained nearly white sandstone, somewhat calcareous	630	640
	Bottom of Bradford First sand		640
44	Greenish-gray sandy shale, fossiliferous	640	684
5	Fine-grained light greenish-gray sandstone, somewhat calcareous	684	689
55	Greenish-gray shale, sparingly fossiliferous	689	744
6	Fine-grained light-gray sandstone, somewhat calcareous	744	750
20	Greenish-gray sandy shale	750	770
5	Fine-grained light greenish-gray sandstone, somewhat calcareous	770	775
41	Greenish-gray sandy shale, fossiliferous	775	816
6	Fine-grained light greenish-gray sandstone, somewhat calcareous	816	822
6	Greenish-gray sandy shale	822	828
87	Greenish-gray shale, fossiliferous	828	915
6	Fine-grained light gray sandstone, calcareous	915	921
36	Greenish-gray shale	921	957
16	Greenish-gray sandy shale, fossiliferous	957	973
7	Fine-grained light-gray sandstone, calcareous	973	980
20	Greenish-gray shale, fossiliferous	980	1000
5	Fine-grained light gray sandstone, calcareous	1000	1005
11	Greenish-gray shale	1005	1016
6	Fine-grained light-gray sandstone	1016	1022
30	Greenish-gray shale	1022	1052
16	Fine-grained light-gray sandstone, calcareous	1052	1068
11	Greenish-gray sandy shale, fossiliferous	1068	1079
35	Greenish-gray shale	1079	1114
16	Fine-grained light chocolate-brown sandstone, fossiliferous and calcareous (Richburg Stray sand)	1114	1130
26	Greenish-gray shale	1130	1156
28	Fine-grained chocolate-brown sandstone, fossiliferous and calcareous; show of gas (Richburg sand)	1156	1184
84	Greenish-gray shale	1184	1268
6	Fine-grained chocolate-brown sandstone (Clarksville sand)	1268	1274
118	Greenish-gray shale	1274	1392
14	Fine-grained chocolate-brown sandstone, somewhat calcareous, with a four-foot layer of greenish-gray shale at middle (Upper Waugh and Porter sand)	1392	1406
92	Greenish-gray shale, with some interbedded thin layers of fine-grained light grayish-brown sandstone	1406	1498
10	Fine-grained chocolate-brown sandstone, fossiliferous and somewhat calcareous (Lower Waugh and Porter sand)	1498	1508
44	Greenish-gray shale	1508	1552
40	Greenish-gray sandy shale	1552	1592
145	Interbedded gray to very dark gray sandy shale and shale	1592	1737
6	Grayish-black shale	1737	1743
26	Very dark gray sandy shale	1743	1769
25	Very dark gray shale, with some interbedded light-gray sandy shale	1769	1794
47	Greenish-gray sandy shale, with some interbedded grayish-black shale	1794	1841
5	Very fine grained light greenish-gray sandstone, somewhat calcareous	1841	1846
9	Greenish-gray sandy shale	1846	1855
28	Interbedded gray shale and sandy shale	1855	1883
38	Greenish-gray sandy shale	1883	1921
7	Grayish-black shale	1921	1928
168	Greenish-gray sandy shale, calcareous	1928	2096
38	Gray shale	2096	2134
12	Grayish-black shale	2134	2146

Gilbert No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
27	Greenish-gray sandy shale, somewhat calcareous	2146	2173
	Bottom of Chemung group		2173
17	Gray shale	2173	2190
14	Greenish-gray sandy shale, calcareous	2190	2204
66	Gray shale, with some interbedded greenish-gray sandy shale	2204	2270
22	Greenish-gray sandy shale, calcareous	2270	2292
93	Gray to greenish-gray shale, and sandy shale	2292	2385
	Bottom of Wiscoy shale		2385
6	Very fine grained light greenish-gray sandstone, somewhat calcareous	2385	2391
12	Greenish-gray sandy shale	2391	2403
7	Very fine grained light greenish-gray sandstone, somewhat calcareous	2403	2410
15	Greenish-gray shale, with some interbedded grayish-black shale	2410	2425
7	Very fine grained light brownish-gray sandstone	2425	2432
58	Greenish-gray sandy shale	2432	2490
7	Grayish-black shale, with considerable interbedded greenish-gray shale	2490	2497
51	Dark-gray shale	2497	2548
8	Grayish-black shale, with some interbedded greenish-gray shale	2548	2556
86	Gray to dark-gray shale, with a little interbedded greenish-gray sandy shale and very fine grained greenish-gray sandstone	2556	2642
8	Very fine grained brownish-gray sandstone	2642	2650
	Bottom of Nunda sandstone		2650
8	Greenish-gray sandy shale	2650	2658
50	Gray to dark-gray shale, with some interbedded greenish-gray sandy shale	2658	2708
8	Very fine grained brownish-gray sandstone, somewhat calcareous	2708	2716
16	Gray sandy shale	2716	2732
25	Gray shale	2732	2757
15	Greenish-gray sandy shale	2757	2772
14	Gray to dark-gray shale	2772	2786
7	Grayish-black shale, with some interbedded gray shale	2786	2793
151	Gray shale with a little interbedded gray sandy shale and very fine grained sandstone	2793	2944
	Bottom of Gardeau flags and shale		2944
9	Gray shale with some interbedded very fine grained gray sandstone	2944	2953
35	Gray shale	2953	2988
8	Grayish-black shale with some interbedded gray shale	2988	2996
79	Gray shale with a little interbedded very fine grained gray sandstone	2996	3075
8	Grayish-black shale with some interbedded gray shale	3075	3083
11	Gray shale	3083	3094
7	Grayish-black shale, with some interbedded gray shale	3094	3101
119	Gray to very dark gray shale, with a little interbedded very fine grained gray sandstone	3101	3220
	Bottom of Hatch flags and shale		3220
16	Grayish-black to black shale	3220	3236
6	Gray shale	3236	3242
31	Grayish-black to black shale	3242	3273
7	Gray shale	3273	3280
7	Grayish-black shale	3280	3287
23	Gray shale	3287	3310
8	Grayish-black shale	3310	3318
8	Gray to very dark gray shale	3318	3326
6	Grayish-black shale	3326	3332
	Bottom of Rhinestreet black shale		3332
99	Gray to dark-gray shale	3332	3431
14	Grayish-black shale	3431	3445
171	Dark-gray shale, calcareous	3445	3616
6	Grayish-black shale	3616	3622
29	Very dark gray shale	3622	3651
	Bottom of Cashaqua shale		3651
60	Grayish-black shale	3651	3711
12	Very dark gray shale	3711	3723
24	Grayish-black shale	3723	3747
	Bottom of Middlesex black shale		3747

Gilbert No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
23	Gray to dark-gray shale	3747	3770
57	Dark-gray shale, calcareous	3770	3827
	Bottom of West River shale and of Portage group		3827
77	Grayish-black shale, calcareous	3827	3904
24	Grayish-black shale, somewhat calcareous	3904	3928
23	Grayish-black shale	3928	3951
27	Black shale, calcareous	3951	3978
12	Black shale, slightly calcareous	3978	3990
	Bottom of Genesee black shale		3990
18	Dense grayish-brown limestone (Tully)	3990	4008

Record of Gilbert No. 1 well below top of Tully Limestone

(Based upon drillers' log.)

	Depth in feet Top	Depth in feet Bottom
Tully limestone	3990	4045
Hamilton group	4045	4538
Onondaga limestone	4538	4630
Oriskany sandstone	4630	4638
Salina group including Cobleskill limestone	4638	5480
Lockport dolomtie	5480	5776
Clinton group	5776	6024
Medina group	6024	6158
Well stopped in Queenston red shale at a total depth of		6250

Record of Sawyer No. 1 Well

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
3728	No samples collected	0	3782
	Top of Richburg sand at 1008 feet		
10	Grayish-black shale, somewhat calcareous	3782	3792
24	Grayish-black shale	3792	3816
34	Grayish-black shale, calcareous	3816	3850
	Bottom of Genesee black shale		3850
32	Dense grayish-brown limestone (Tully)	3850	3882
5	Very dark brownish-gray shale	3882	3887
6	Grayish-black shale, somewhat calcareous	3887	3893
6	Very dark gray shale, calcareous	3893	3899
6	Grayish-black shale, somewhat calcareous	3899	3905
13	Grayish-black shale, calcareous	3905	3918
5	Grayish-black shale, very calcareous	3918	3923
5	Grayish-black shale, calcareous	3923	3928
19	Very dark gray shale, calcareous	3928	3947
6	Grayish-black shale, calcareous	3947	3953
5	Dense brownish-gray limestone (Tichenor)	3953	3958
5	Dark-gray shale, very calcareous	3958	3963
6	Dark-gray shale, calcareous	3963	3969
29	Very dark gray shale, very calcareous	3969	3998
30	Grayish-black shale, very calcareous	3998	4028
3	Grayish-black shale, calcareous	4028	4031
20	Very dark gray shale, calcareous	4031	4051
6	Grayish-black shale, calcareous	4051	4057
6	Very dark gray shale, calcareous	4057	4063
18	Grayish-black shale, calcareous	4063	4081
12	Very dark gray shale, calcareous	4081	4093
24	Grayish-black shale, calcareous	4093	4117
34	Very dark shale, calcareous	4117	4151
27	Grayish-black shale, calcareous	4151	4178
18	Very dark gray shale, calcareous	4178	4196
8	Dense, dark grayish-brown limestone, with one foot of interbedded grayish-black calcareous shale at middle	4196	4204
21	Black shale, calcareous	4204	4225
10	Grayish-black shale, calcareous	4225	4235
30	Black shale, calcareous, with a thin seam of dense, light-brown limestone near base	4235	4265
20	Grayish-black shale, calcareous	4265	4285
19	Black shale, calcareous	4285	4304
6	Black shale, calcareous, with a few thin seams of dense, light grayish-brown limestone (Stafford)	4304	4310

Sawyer No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bottom
15	Black shale, calcareous	4310	4325
10	Grayish-black shale, calcareous	4325	4335
10	Black shale, calcareous	4335	4345
2	Black shale, brecciated, minute fractures filled with calcite; large gas pocket encountered at this horizon	4345	4347
	Bottom of Hamilton group		4347
86	Very fine crystalline, brownish-gray siliceous limestone, cherty in lower part	4347	4433
	Bottom of Onondaga limestone		4433
5	Fine to medium-grained quartz sandstone, calcareous	4433	4438
	Bottom of Oriskany sandstone		4438
18	Very fine, crystalline, grayish-brown to dark grayish-brown limestone (Cobleskill)	4438	4456
	Top of Salina group	4456	
14	Very fine, crystalline, light-gray limestone	4456	4470
28	Very fine, crystalline, dark brownish-gray limestone	4470	4498
	Bottom of Bertie water lime		4498
76	Very fine, crystalline, dark brownish-gray argillaceous magnesian limestone and dolomite, contains anhydrite	4498	4574
11	Very fine, crystalline, gray to dark-gray argillaceous limestone, contains anhydrite	4574	4585
45	Very fine, crystalline, brownish-gray argillaceous limestone, contains anhydrite	4585	4630
110	Very fine, crystalline, dark grayish-brown argillaceous magnesian limestone and dolomite, contains anhydrite	4630	4740
5	Medium to coarse, crystalline salt	4740	4745
10	Very fine, crystalline, dark brownish-gray argillaceous limestone, contains anhydrite	4745	4755
56	Medium, crystalline salt	4755	4811
5	Light-gray shale, slightly calcareous	4811	4816
31	Very fine, crystalline, light-gray argillaceous limestone	4816	4847
	Well stopped in Camillus formation at a total depth of		4847

The base of the Dunkirk beds in the Gilbert well has been placed at a depth of 2173 feet at the bottom of a sandy shale bed, 27 feet thick, that is thought to occupy the horizon of the Long Beards Riffs sandstone which crops out 24 miles to the north along the Genesee River at Long Beards Riffs, half a mile south of Fillmore.[87] The bed underlies approximately 400 feet of gray shales in large part sandy in which occasional layers of black shale are interstratified, a succession of beds that closely resembles lithologically the lower 400 feet of Chemung strata as described by Clarke and Luther[88] from outcrops in the Genesee Valley section to the north. Chadwick[89] has traced this horizon westward along the outcrop and correlated it with the Dunkirk black shale of the Lake Erie section.

At Long Beards Riffs, the base of the Chemung group, as determined by Luther, occurs 1170 feet above sea-level, while in the Gilbert well, it has been placed 100 feet below sea-level. This represents a descent toward the south of 1270 feet in 24 miles, an average of 53 feet per mile. In a well recently completed by S. J. Brendel on the Arthur Sheldon farm (see Section No. 13) one mile north of West Allen and 20 miles slightly east of north of the Gilbert well, the top of the Oriskany sandstone was encountered

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[87] D. Dana Luther, Stratigraphy of Portage formation between the Genesee Valley and Lake Erie; New York State Mus. Bull. 69, 1903, p. 1009.

[88] John M. Clarke and D. Dana Luther, Geologic map and description of the Portage and Nunda Quadrangles; New York State Mus. Bull. 118, 1908, p. 67.

[89] George H. Chadwick, The stratigraphy of the Chemung group in western New York. New York State Mus. Bull. 251, 1924, pp. 149-150.

1331 feet below sea-level, while in the Gilbert well this horizon was struck 2558 feet below sea-level, giving a descent toward the south of 1210 feet or an average of 61 feet per mile for the deeper horizon. The difference can in part at least be accounted for by the thickening of the Portage group southward.

As Ashburner[90] pointed out many years ago, the Richburg sand, the main producing horizon in the Richburg oil pool in Allegany County, New York, occupies approximately the same stratigraphic position as does the Bradford Third sand. In the Gilbert well, the top of the Richburg sand occurs 1216 feet below the base of the Cattaraugus formation while in the Derrick City well the interval between the base of the Cattaraugus and the top of the Bradford Third sand is 1245 feet.

Section No. 13

Section No. 13 was obtained in a well drilled on the Arthur Sheldon farm in the Town of Allen, Allegany County, New York, one mile north of West Allen, at an elevation of 1620 feet, by S. J. Brendel and associates during the fall of 1932. An open flow of 200,000 cubic feet of gas per day and some salt water was encountered in the Oriskany sandstone. The following record is based upon the study made of a complete set of samples of the cuttings.

Record of Arthur Sheldon No. 1 Well

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
7	Soil	0	7
63	Fine-grained, bluish-gray sandstone, fossiliferous	7	70
15	Greenish-gray sandy shale	70	85
10	Fine-grained, light greenish-gray sandstone slightly calcareous	85	95
7	Fine-grained, light grayish-brown sandstone, slightly calcareous	95	102
5	Greenish-gray sandy shale	102	107
23	Very fine grained, light grayish-brown sandstone, slightly calcareous, with some interbedded greenish-gray sandy shale	107	130
54	Greenish-gray sandy shale	130	184
18	Greenish-gray shale	184	202
8	Very fine grained greenish-gray sandstone	202	210
14	Gray shale	210	224
24	Gray shale, with some interbedded greenish-gray sandy shale	224	248
24	Gray shale	248	272
6	Dark-gray sandy shale	272	278
7	Greenish-gray sandy shale	278	285
23	Dark to very dark gray sandy shale	285	308
6	Grayish-black shale	308	314
6	Gray to dark-gray sandy shale	314	320
42	Gray to very dark gray shale	320	362
8	Dark-gray sandy shale	362	370
15	Very fine grained, light gray sandstone, slightly calcareous	370	385
8	Greenish-gray sandy shale	385	393
6	Very fine-grained gray sandstone, slightly calcareous	393	399
12	Dark-gray shale	399	411
12	Gray sandy shale	411	423
37	Interbedded gray shale and sandy shale	423	460
21	Very fine grained light-gray sandstone	460	481
5	Very dark gray, almost black, shale	481	486
31	Gray to dark-gray sandy shale	486	517
6	Grayish-black shale	517	523
11	Gray to dark-gray sandy shale	523	534
6	Gray shale	534	540

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[90] Charles A. Ashburner, The geologic distribution of natural gas in the United States; Trans. A.I.M.E., vol. XV, 1887, p. 519.

Arthur Sheldon No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet	
		Top	Bottom
17	Greenish-gray sandy shale	540	557
24	Gray shale	557	581
12	Grayish-black shale	581	593
6	Greenish-gray sandy shale	593	599
6	Very fine grained greenish-gray sandstone, somewhat calcareous	599	605
12	Greenish-gray sandy shale	605	617
6	Very fine-grained greenish-gray sandstone, slightly calcareous	617	623
12	Gray shale	623	635
6	Greenish-gray sandy shale	635	641
25	Very fine grained greenish-gray sandstone, slightly calcareous	641	666
18	Gray sandy shale	666	684
18	Very fine grained light greenish-gray sandstone, slightly calcareous	684	702
6	Gray sandy shale	702	708
6	Very fine grained light greenish-gray sandstone	708	714
12	Gray sandy shale	714	726
5	Gray shale	726	731
6	Gray sandy shale	731	737
18	Dark to very dark gray shale	737	755
35	Grayish-black shale	755	790
10	Very fine grained light greenish-gray sandstone	790	800
	Bottom of Dunkirk beds and of Chemung group		800
175	Gray sandy shale	800	975
	Bottom of Wiscoy shale		975
6	Very fine grained gray sandstone, slightly calcareous	975	981
18	Gray sandy shale	981	999
6	Very fine grained greenish-gray sandstone, slightly calcareous	999	1005
18	Gray shale	1005	1023
47	Very fine grained grayish-brown sandstone, slightly calcareous	1023	1070
20	Gray sandy shale	1070	1090
20	Gray shale	1090	1110
10	Gray sandy shale	1110	1120
10	Brownish-black shale	1120	1130
10	Gray shale	1130	1140
6	Very fine grained grayish-brown sandstone, somewhat calcareous	1140	1146
12	Gray sandy shale	1146	1158
7	Very fine grained grayish-brown sandstone, somewhat calcareous	1158	1165
	Bottom of Nunda sandstone		1165
88	Gray shale, with some interbedded very dark gray shale	1165	1253
67	Gray sandy shale	1253	1320
	Bottom of Gardeau flags and shale		1320
10	Very fine grained grayish-brown sandstone, slightly calcareous	1320	1330
10	Gray shale	1330	1340
10	Very fine grained grayish-brown sandstone, slightly calcareous	1340	1350
	Bottom of Grimes sandstone		1350
10	Gray shale	1350	1360
30	Gray sandy shale	1360	1390
20	Gray shale	1390	1410
10	Dark-gray sandy shale	1410	1420
40	Gray to dark-gray shale	1420	1460
20	Dark-gray shale	1460	1480
20	Very dark gray shale	1480	1500
10	Gray shale	1500	1510
70	Very dark gray shale	1510	1580
10	Dark-gray shale	1580	1590
10	Dark gray sandy shale	1590	1600
20	Gray to dark-gray shale	1600	1620
10	Very dark gray shale	1620	1630
30	Gray to dark-gray shale	1630	1660
40	Dark-gray shale	1660	1700
	Bottom of Hatch shale		1700
10	Very dark gray shale	1700	1710
20	Dark-gray shale	1710	1730
30	Very dark gray shale	1730	1760
20	Gray to dark-gray shale	1760	1780

Arthur Sheldon No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in feet Top	Bottom
10	Very dark gray, almost black, shale	1780	1790
10	Gray to dark-gray shale	1790	1800
10	Dark-gray shale	1800	1810
10	Grayish-black shale	1810	1820
	Bottom of Rhinestreet black shale		1820
20	Dark to very dark gray shale	1820	1840
20	Gray to dark-gray shale	1840	1860
20	Dark-gray shale	1860	1880
20	Gray sandy shale, slightly calcareous	1880	1900
20	Gray shale, slightly calcareous	1900	1920
20	Dark-gray shale, slightly calcareous	1920	1940
20	Gray shale, slightly calcareous	1940	1960
50	Dark-gray shale, slightly calcareous	1960	2010
10	Black shale, slightly calcareous	2010	2020
20	Dark-gray shale, slightly calcareous	2020	2040
20	Dark-gray shale	2040	2060
	Bottom of Cashaqua shale		2060
70	Very dark gray shale	2060	2130
10	Grayish-black shale	2130	2140
	Bottom of Middlesex black shale		2140
20	Dark-gray shale	2140	2160
20	Dark-gray shale, somewhat calcareous	2160	2180
10	Dark-gray sandy shale, somewhat calcareous	2180	2190
20	Very dark gray shale, slightly calcareous	2190	2210
20	Dark-gray shale, somewhat calcareous	2210	2230
10	Very dark gray shale, calcareous	2230	2240
	Genundewa horizon—Bottom of West River shale and Portage group		2240
20	Very dark gray, almost black, shale, somewhat calcareous	2240	2260
10	Dark-gray shale, somewhat calcareous	2260	2270
20	Very dark gray, almost black, shale	2270	2290
20	Grayish-black shale	2290	2310
20	Grayish-black shale, somewhat calcareous	2310	2330
10	Black shale, somewhat calcareous	2330	2340
	Bottom of Genesee black shale		2340
20	Very fine, dense, grayish-brown limestone	2340	2360
18	Very fine, dense, dark grayish-brown limestone	2360	2378
26	Very fine, dense, dark brownish-gray platy limestone, with some interbedded very dark gray calcareous shale	2378	2404
	Bottom of Tully limestone		2404
26	Dark-gray shale, calcareous	2404	2430
50	Dark-gray shale, slightly calcareous	2430	2480
6	Very fine, dense, brownish-gray fossiliferous limestone (Tichenor)	2480	2486
	Bottom of Moscow formation		2486
133	Dark-gray and very dark-gray shale, somewhat calcareous	2486	2619
4	Very fine, dense, dark brownish-gray fossiliferous limestone—Center field	2619	2623
	Bottom of Ludlowville formation		2623
20	Very dark gray shale, somewhat calcareous	2623	2643
93	Very dark gray shale, calcareous	2643	2736
9	Grayish-black shale, somewhat calcareous	2736	2745
10	Very dark gray shale, somewhat calcareous	2745	2755
45	Very dark gray shale, calcareous	2755	2800
17	Very dark gray shale, somewhat calcareous	2800	2817
4	Very fine, dense, brownish-gray fossiliferous limestone (Stafford)	2817	2821
	Bottom of Skaneateles formation		2821
9	Very dark gray shale, slightly calcareous	2821	2830
10	Grayish-black shale, slightly calcareous	2830	2840
10	Black shale, slightly calcareous	2840	2850
6	Grayish-black shale	2850	2856
	Bottom of Marcellus formation and Hamilton group		2856
61	Very fine, dense, dark brownish-gray limestone	2856	2917
6	Very fine, dense, very dark gray argillaceous limestone	2917	2923
28	Very fine, dense, brownish-gray cherty limestone	2923	2951
	Bottom of Onondaga limestone		2951
21	Fine- to medium-grained, light-gray sandstone, somewhat calcareous (Oriskany)	2951	2972
23	Very fine, crystalline, light brownish-gray to brownish-gray magnesian limestone (Cobleskill)	2972	2995

Arthur Sheldon No. 1 Well (cont.)

Thickness feet	Description of strata	Depth in fee Top	Bottom
	Top of Salina group	2995	
32	Very fine, dense, grayish-brown to dark grayish-brown argillaceous magnesian limestone (Bertie)	2995	3027
	Well stopped in Salina group at total depth of....		3027

The base of the Dunkirk beds has been placed at a depth of 800 feet in the Sheldon well at the bottom of a very fine grained light greenish-gray sandstone ten feet thick, which, it is thought, represents the horizon of the Long Beards Riffs sandstone. At Long Beards Riffs, south of Fillmore, this horizon occurs at an elevation of 1170 feet, while in the Sheldon well it has been placed at 820 feet. This represents a descent toward the southeast of 350 feet in 6 miles, an average of 58 feet per mile.

In subdividing the Hamilton group in the Sheldon well, the sections measured by Cooper[91] along the outcrop to the north have been of inestimable value and his correlations have been adopted.

The thicknesses of the major sub-divisions of the Devonian and Silurian systems in the thirteen deep well sections described are summarized in Table 5.

DEVONIAN SYSTEM

UPPER DEVONIAN

CHEMUNG GROUP (CHAUTAUQUAN)

In McKean, northern Elk, and western Potter Counties, the bottom of the Cattaraugus formation, the base of the Catskill type of red beds, appears to represent a nearly contemporaneous plane of deposition and hence can be used for correlation purposes. To the east and southeast of this area, the red beds descend progressively lower and lower in the geologic column. To the west they become less and less conspicuous and finally disappear.

D. Dana Luther,[92] in 1902, on the evidence of fossils, placed the bottom of the Chemung at the base of the Long Beards Riffs sandstone which crops out along Genesee River, half a mile south of Fillmore in northern Allegany County, New York. Chadwick[93] has shown that the base of the Dunkirk black shale of the Lake Erie section corresponds in stratigraphic position to the base of the Long Beards Riffs sandstone. In 1924, Chadwick agreed with Luther that the base of the latter represents the bottom of the Chemung group. More recent and detailed studies by Chadwick in central and western New York have led him to the conclusion that the base of the Chemung group occurs at the base of the Grimes sandstone, hitherto considered to lie at about the middle of the Portage group.[94]

It has been customary in western Pennsylvania to include all the strata from the top of the Portage group to the base of the Cattaraugus formation or its equivalent to the west, the Venango, in the Chemung group. Attention

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[91] G. Arthur Cooper, Stratigraphy of the Hamilton group in New York: American Jour. Sci., vol. XIX, 1930, p. 218.

[92] D. Dana Luther, Stratigraphy of Portage formation between the Genesee Valley and Lake Erie: New York State Mus. Bull. 69, 1903, p. 1009.

[93] G. H. Chadwick, The stratigraphy of the Chemung group in western New York: New York State Mus. Bull. 251, 1924, pp. 149-150.

[94] G. H. Chadwick, Great Catskill Delta; and revision of later Devonic succession, III, Revised Correlations: Pan-American Geologist, vol. LX, 1933, p. 353. Chemung is Portage: Bull. Geol. Soc. America, vol. 46, pp. 343-354, 1935.

Table 5. Thicknesses in feet of major subdivisions of Devonian and Silurian Systems

Section Number	1	2	3	4	5	6	7	8	9	10	11	12	13
MISSISSIPPIAN SYSTEM													
Cussewago—Knapp										200			
DEVONIAN SYSTEM													
Conewango group													
Oswayo										170			
Cattaraugus						105+			263+	327	56+		
Chemung group	2077	783+	1851+	3960	1980+	2083	4190	2400	4251	2308	2497	2233	800+
Portage group	883	686			1638	1616		1817		1768	1815	1654	1440
Genesee	absent	absent			125	77		125	140	99	199	163	100
Tully	absent	absent			5	4		18	4	6	48	32	64
Hamilton group	420	341			427	490		458	465	440	532	465	452
Onondaga	154	160	225	133	101	78	70	48	59	82	27	86	95
Oriskany	absent	absent	absent	absent	15	17	20	absent	absent	absent	5	5	21
Helderberg group	absent	absent	absent	absent	5+		60	57	60	20	66	absent	absent
SILURIAN SYSTEM													
Cobleskill	9	6	548	774			20	25	27	28	5	18	23
Salina group	667	490					850	317+		1132	300+	824	32+
Lockport	274	195	226	248			300			320		296	
Clinton group	140	111	100	120			175			176		248	
Medina group	89+	118	110	113			140			166		134	
ORDOVIDIAN SYSTEM													
Queenston		18+	21+	129+			120+			688+		92+	

must be called to the fact that the upper beds thus included are younger than the Chemung beds of the type locality around the sides of Narrow Hill, at Chemung Narrows, west of Chemung, in south-central New York. This necessarily follows, since, as has been pointed out, the Catskill type of sedimentation, of which the Cattaraugus represents only the last stage, began progressively earlier as one goes eastward and southeastward. Chadwick now thinks that the base of the Dunkirk black shale represents the top of the Chemung group instead of the bottom; that outcrops of the highest true Chemung barely enter Chautauqua County, the type area of the Chautauquan series of the Upper Devonian; and that, therefore, this series cannot be considered to contain any strata of true Chemung age.[95] While the older grouping is the one that has been retained for the present, it is realized that a revision of the nomenclature now in use will have to be made after a thorough restudy of the Upper Devonian stratigraphy of New York and Pennsylvania has been completed.

The Chemung group in the Bradford district consists of a series of interbedded greenish-gray and gray shales and sandy shales, fine-grained light-gray sandstones, and fine-grained chocolate-brown sandstone. The total thickness is approximately 2100 feet. Sandstones occur more abundantly in the upper and middle portions than in the lower. In the basal portions, layers of grayish-black shale are present, which may represent the Dunkirk shale horizon. Although marine fossils occur throughout the entire thickness, they are much more abundant in the upper half than in the lower.

The oil- and gas-bearing sands of the district occupy a little over 1000 feet in the middle of the group. The Bradford First sand lies about 650 feet below the top of the group and the Haskell or Bradford Sixth about 400 feet above its base.

The Bradford First sand occupies approximately the stratigraphic position of the Cuba sandstone, which is well developed near Cuba in Allegany County, New York, where once it was quarried for building stone. The oil of the famous Seneca oil spring, 1½ miles northwest of Cuba, apparently issues from this sandstone. Cuba is 15 miles northeast of the Bradford pool. On his stratigraphic map of the Olean quadrangle Glenn[96] shows the outcrop of the Cuba sandstone at Cuba at an elevation of 1560 feet and the Wolf Creek conglomerate, the basal member of the Cattaraugus formation, on a hill, 2½ miles southwest of Cuba, at an elevation of 2140 feet. Here the interval between the top of the Chemung and the Cuba sandstone is 580 feet, assuming that the strata are essentially horizontal, or approximately the same as the interval between the top of the Chemung and the Bradford First sand in the Bradford district.

That the Bradford Third sand was deposited under marine conditions is indicated by the fact that marine fossils are distributed, although very sparingly, throughout the main body of sand in many parts of the field. Fragments of carbonized plant remains are also present. These are presumably of land origin, their fragmentary nature indicating that they were transported to their present environment by streams, waves and currents. Just above the sand itself, in places separated from it by a few inches of shale, usually there are one or more thin beds of fine-grained gray calcareous sandstone which contain an abundance of marine shells.

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[95] G. H. Chadwick, Idem. p. 351.

[96] L. C. Glenn, Stratigraphic map of the Olean Quadrangle: New York State Mus. Bull. 69, 1903.

In core samples of the Bradford Third sand, collected by Messrs. Jerry B. Newby and Paul D. Torrey, Charles Butts[97] has identified the following fossils:—*Productella lachrymosa, Productella hirsuta?, Camarotoechia contracta, Spirifer mesacostalis, Edmondia obliqua (?).*

In a collection of fossils obtained by the writer from cores of the cap-rock above the Bradford Third sand the following forms were present:—[98] *Schuchertella chemungensis, Productella lachrymosa (?), Dalmanella tioga (?), Camarotoechia contracta, Leiorhynchus mesicostale, Cryptonella (?), Spirifer mesacostalis.*

Comparing the above assemblage with fossils listed from the Portage and Chemung groups in central New York and adjacent parts of Pennsylvania, it is found that although some of the forms are already present in beds of Portage age, they all continue well up into the Chemung.[99]

In discussing Section 2, it has been pointed out that the Bradford Third sand occupies approximately the horizon of the Laona sandstone on the outcrop.

The Chemung group maintains a fairly uniform thickness over the area covered by the deep well sections shown on Plate 12. Between sections 1 and 12 the eastward thickening in 41 miles is only 156 feet or 3.8 feet per mile and between sections 10 and 11 it is 189 feet in 41 miles or 4.6 feet per mile. Southward thickening is somewhat greater. Between sections 1 and 10 it is 231 feet in 37 miles or 6.2 feet per mile and between sections 12 and 11 it is 264 feet in 22 miles or 12 feet per mile.

PORTAGE GROUP

The term Portage group has been used to designate the strata between the bottom of the Genundewa limestone horizon and the base of the Chemung as delimited by Clarke and Luther in the Genesee valley section.[100] As has been pointed out under the description of the Chemung group, this classification will require revision after the investigations of the various workers now engaged in the study of the Upper Devonian of New York and Pennsylvania have been completed.

In the Bradford district the upper half of the Portage group consists predominatingly of gray to dark-gray and greenish-gray shales with some interbedded sandy shales and fine-grained sandstones. Black shales form a prominent part of the lower half. The total thickness of the group in the district is about 1600 feet.

The Portage group thickens rather rapidly to the southeast in the region of which the Bradford district is a part. In the Lake Erie section, 35 miles slightly west of north of section 1, the group, as delimited by Chadwick

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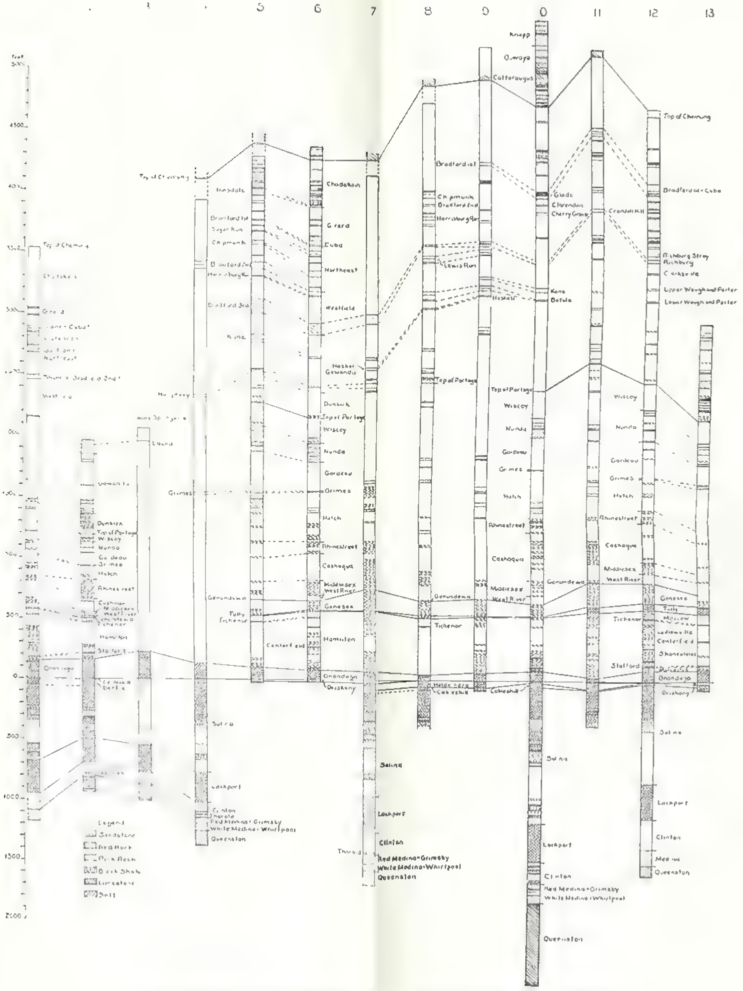
[97] Charles Butts. Written communication, April 8 and November 3, 1926.

[98] Charles Butts. Written communication, December 10, 1929.

[99] Henry S. Williams, Ralph S. Tarr, and Edward M. Kindle, Description of the Watkins Glen-Catatonk District: Folio 169. U. S. Geol. Survey, 1909, p. 6.
Bradford Willard, Devonian faunas in Pennsylvania: Pennsylvania Geol. Survey, Fourth Series, Bull. G4, 1932, pp. 22-29.

[100] John M. Clarke and D. Dana Luther, Geologic map and description of the Portage and Nunda Quadrangles: New York State Mus. Bull. 118, 1908, pp. 46-47.

PLATE 12



Graphic representation of 13 deep well sections in western New York and northwestern Pennsylvania.

in 1924, has a thickness of only 515 feet.[1] At section 1 the thickness is 883 feet, whereas at section 10, 37 miles S. 15° E. of 1, it is 1768 feet. At section 2, the thickness is 686 feet, whereas at section 12, 45 miles southeast of 2, it is 1654 feet and at section 11, 22 miles slightly east of south of 12, it is 1815 feet.

GENESEE BLACK SHALE

The term "Genesee" has been restricted to the black shales between the base of the Genundewa limestone and the top of the Tully.[2] In the Bradford district this formation ranges from 75 to 125 feet in thickness.

TULLY LIMESTONE

Throughout north-central Pennsylvania the Tully limestone is an excellent horizon marker for separating the Upper from the Middle Devonian. The greatest thicknesses of limestone at this horizon in the deep well sections have been encountered in Bradford and Clearfield Counties, namely, 130 and 150 feet respectively. Willard has recently identified this horizon on the outcrop between Jersey Shore and Lockhaven in Lycoming and Clinton Counties where it is represented by approximately 200 feet of limestone.[3] Tully limestone can be recognized as far west as Bradford and Kane. Here it has thinned to less than 5 feet. Still farther west it disappears entirely.

MIDDLE DEVONIAN

HAMILTON GROUP

The Hamilton group includes the strata lying between the base of the Tully horizon and the top of the Onondaga limestone. In the Bradford district this group consists of from 425 to 500 feet of dark gray and black shales.

ONONDAGA LIMESTONE

The Onondaga limestone is an excellent horizon marker over the entire Bradford district. It has a thickness from 70 to 100 feet and consists of a very fine, crystalline, light gray to dark brownish-gray cherty limestone.

LOWER DEVONIAN

ORISKANY SANDSTONE

Fifteen feet of fine to medium-grained, light-gray sandstone with a good show of oil were encountered in the Quinlan deep well, seventeen feet with no fluids in the Ryder-Scott, and 20 feet with a show of oil in the Derrick City well. The northern limit of the Oriskany sandstone probably lies not far north of these wells as no sandstone was encountered in the Hotchkiss and Autman wells at localities 1 and 4. It is probably absent in the southern part of the Bradford district as no sandstone was present at this horizon in the Zerbe, Haywood, and Kane deep wells at localities 8, 9, and 10 respectively.

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[1] D. Dana Luther, Stratigraphy of Portage formations between the Genesee Valley and Lake Erie: New York State Mus. Bull. 69, 1903, p. 1028.

George H. Chadwick, The stratigraphy of the Chemung group in western New York: New York State Mus. Bull. 251, 1924, p. 149.

[2] John M. Clarke and D. Dana Luther, Idem, p. 49.

[3] Bradford Willard, Portage group in Pennsylvania: Bull. Geol. Soc. America, vol. 46, pp. 1209-1212, 1935.

HELDERBERG GROUP

The Helderberg limestone probably is present in the Bradford district immediately below the Oriskany sandstone but is thin. Sixty feet of strata have been tentatively assigned to this group in the log of the Derrick City well. As a complete set of samples of the cuttings was not available for examination, this figure can be considered only approximate.

SILURIAN SYSTEM

COBLESKILL LIMESTONE

In the area of which the Bradford district is a part, a magnesian limestone occurring at the top of the Silurian system is thought to represent the Cobleskill limestone of western New York. Along the outcrop of the Silurian system, 70 miles to the north, this limestone has a thickness of 5 feet and is the highest member of the system.[4] In the log of the Derrick City well, a thickness of 20 feet has been tentatively assigned to it.

SALINA GROUP

The Salina group, as developed in the Bradford district, consists of a series of interbedded dense, argillaceous, magnesian limestones, ranging in color from light gray to dark grayish-brown, and gray shales, for the most part either calcareous or dolomitic, 850 feet thick. Beds of anhydrite and rock salt also are present. Along the outcrop, 70 miles to the north, the thickness of the Salina group is only 440 feet,[5] whereas at section 6, four miles south of Kane, it is 1132 feet.

LOCKPORT DOLOMITE

The Lockport dolomite, underneath the Salina group, is a readily recognizable horizon in the Bradford district. It consists of approximately 300 feet of very fine crystalline, brownish-gray to very dark grayish-brown dolomite. Like the Salina group, this formation thickens southward. Along the outcrop on the Niagara gorge section, 70 miles north of the Bradford district, the thickness is only 150 feet,[6] whereas at section 6, four miles south of Kane, it is 320 feet. Swartz[7] has suggested that the McKenzie shale and limestone of central Pennsylvania is the equivalent, at least in part, of the Lockport dolomite.

CLINTON GROUP

The term Clinton group has been applied to the strata between the base of the Lockport dolomite and the top of the Medina sandstone. The group, therefore, includes the Rochester shale at the top as well as the Clinton formation proper. This group in the Bradford district has a thickness of 175 feet and consists mostly of shale which is relatively calcareous in the upper part. A thin bed of limestone is present near the base.

MEDINA GROUP

The Medina group has been restricted to those strata which lie between the top of the Thorold sandstone and the top of the Queenston shale. In the

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[4] E. M. Kindle and Frank B. Taylor, Description of the Niagara Quadrangle: Folio No. 190, U. S. Geol. Survey, 1913, p. 8.

Silurian section near Mount Union, central Pennsylvania: Bull. Geol. Soc. America, vol. 45, 1934, p. 126.

[5] E. M. Kindle, and Frank B. Taylor, idem.

[6] E. M. Kindle and Frank B. Taylor, idem, p. 7.

[7] F. M. Swartz, Correlation of the McKenzie shale: Bull. Geol. Soc. America, vol. 41, 1930, pp. 117-118.

Bradford district the group has very much the same characteristics as in the Niagara section. Drillers usually divide it in their logs, on the basis of color into two parts, the upper part or Grimsby being designated as the Red Medina and the lower or Whirlpool, the White Medina.

In the Niagara gorge section, the red color is confined to the upper 48 feet of sandstones and sandy shales, the lower 46 feet being gray or white.[8]

At Derrick City the upper 82 feet are red and the lower 58 feet gray or white. In the Kane deep well, 110 miles south of the outcrop, the Red Medina has a thickness of 70 feet and the White Medina, 96 feet. As in the Niagara gorge section, the latter is underlain by the Queenston red shale of which 688 feet had been penetrated when drilling stopped.

In the vicinity of Bellefonte, 70 miles southeast of the Kane deep well, the Red Medina has almost disappeared along the outcrop. Swartz[9] has recently proposed the name "Castanea sandstone" for a thin series of red and green sandy beds occasionally found at the top of the Tuscarora sandstone in central Pennsylvania, which probably represent the attenuated edge of the Red Medina. The White Medina, on the other hand, thickens to nearly 600 feet, forming the well-known Tuscarora sandstone, and the underlying Queenston red shales pass into the red shales and sandstones that comprise the Juniata formation.

Attention should here be called to the fact that J. P. Lesley,[10] Director of the Second Pennsylvania Geological Survey, called the Tuscarora sandstone of central Pennsylvania the Medina white sandstone and the Juniata formation, the Medina red sandstone. Lesley's Medina red sandstone is the equivalent of the Queenston red shale and underlies the so-called White Medina of western New York and northwestern Pennsylvania, whereas the so-called Red Medina of the drillers in western New York overlies the White Medina and is probably represented in central Pennsylvania by Swartz's Castanea sandstone.

ORDOVICIAN SYSTEM

QUEENSTON SHALE

The Queenston shale is the oldest formation thus far reached by the drill in the Bradford district. In the Derrick City deep well 120 feet of red sandy shale belonging to this formation had been penetrated when drilling stopped.

Whether the Silurian-Ordovician boundary should be drawn at the top of the Queenston red shale is still a debated question among stratigraphers. Some think it occurs below the Queenston. The New York and Pennsylvania Geological Surveys include the Juniata (Queenston) shale in the Silurian system.[11]

STRUCTURAL GEOLOGY

REGIONAL

The Bradford district is in the northern part of the Appalachian plateau province. Structurally, this province consists of a broad asymmetrical synclinorium or basin, whose long axis trends in a northeasterly and southwesterly direction with the steeper limb on the southeast side. The central part of the plateau, in southeast Ohio, southwest Pennsylvania, and northwest West Virginia, is floored with beds of Permian age, as shown in Figure 5, which are surrounded by outcrops of Pennsylvanian beds. Mississippian, Devonian, Silurian, and older strata crop out in sequence along the western, northern, and eastern margins of the basin.

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[8] E. M. Kindle and Frank B. Taylor, op. cit., p. 6.

[9] F. M. Swartz, Silurian section near Mount Union, central Pennsylvania: Bull. Geol. Soc. America, vol. 45, 1934, p. 109.

[10] J. P. Lesley, A summary description of the geology of Pennsylvania: Final Report, vol. 1, Pennsylvania Second Geol. Survey, 1892, p. 625.

[11] Winifred Goldring, Handbook of paleontology for beginners and amateurs, Part 2: The Formations: New York State Museum Handbook 10, 1931, p. 317. George H. Ashley, A syllabus of Pennsylvania geology and mineral resources: Pennsylvania Topo. and Geol. Survey, Bull. G-1, 1931, p. 62.

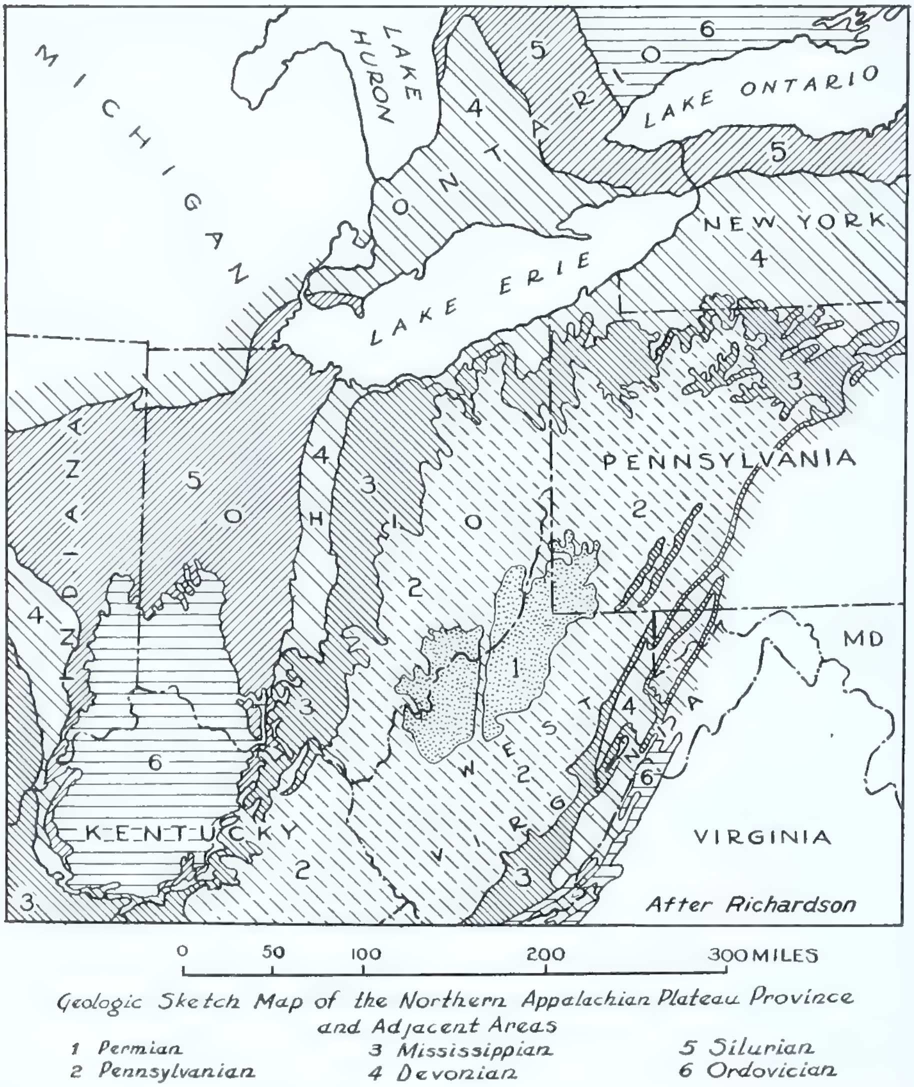

FIGURE 5. **Geologic sketch map of the northern part of the Appalachian Plateau and adjacent region.**

FOLDING

On the southeast the plateau terminates along the Allegheny Front and is adjoined by the closely folded Appalachians. The southeastern limb of the synclinorium in its northern part is modified by a series of rather prominent anticlinal and synclinal foreland folds with axes trending approximately parallel to the long axis of the synclinorium, as shown on Figure 6. Although some of the anticlines rise in places to heights of 2,500 feet or more above the adjoining synclines, folds 300 to 800 feet high are more numerous.[12] The folds become less prominent in the central part of the basin and are hardly perceptible on the northwestern limb.

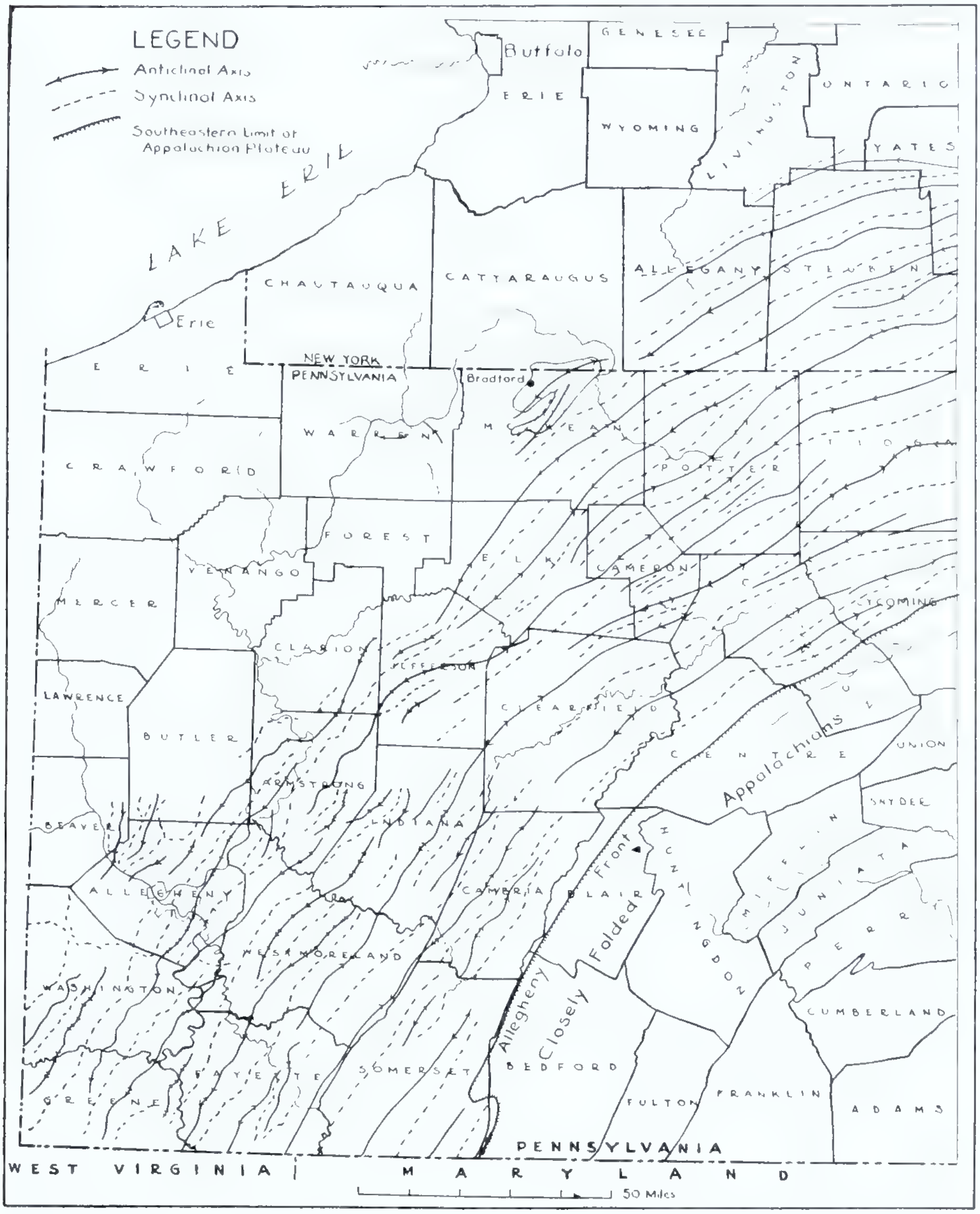

FIGURE 6. **Map showing trend of foreland folds in the northern part of the Appalachian Plateau.**

The foreland folds have trends approximately paralled to those of the closely folded Appalachians to the southeast. They die out gradually northwestward from the Allegheny Front. The same forces which produced the folded and faulted structures of the Appalachian Mountains no doubt caused the development of the foreland folds, and the two structural features, therefore, have a similar age and origin. The foreland folds represent the diminishing activities of tangential compressive forces which originated to the southeast.

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[12] R. E. Sherrill, Symmetry of Northern Appalachian foreland folds: Jour. Geology, vol. XLII, 1934, p. 226.

DIP

The regional dip of the surface formations in the Bradford district is slightly west of south.[13] In well No. 2 (see pl. 11) the top of the Laona sandstone occurs at an elevation of 1518 feet above sea-level and in well No. 7 the top of the Bradford Third sand at 456 feet. If the assumption that these two sandstones occupy the same stratigraphic position in the Upper Devonian strata is correct, this horizon descends 1062 feet in a southerly direction in about 44 miles or an average of 24 feet per mile. Inasmuch as well No. 7 is slightly east of south of No. 2 instead of west, the true regional dip is somewhat greater. Possibly slight difference in locations of the two wells with respect to local structures also changes this figure slightly.

Owing to the fact that most of the underlying formations thicken in a southeasterly direction, the regional dip of the deeper strata swings toward the southeast. This is exemplified by the generalized structure contours drawn on the base of the Onondaga limestone on Plate 11. Similar contours drawn on the top of the Medina sandstone would show a still greater shift toward the southeast. Between wells 2 and 7 the base of the Onondaga descends 2149 feet or an average of 49 feet per mile and the top of the Medina 2762 feet or an average of 63 feet per mile.

Price[14] has shown that the Appalachian structural front, which is only a short distance east of the Allegheny Front, corresponds to the thickest zone of sedimentation from at least early Devonian up through and including Pottsville time. This no doubt is largely responsible for the east component of the regional dip of the deeper strata in the Bradford district. After Pottsville time, the zone of maximum subsidence apparently shifted westward inasmuch as the highest strata, namely the Permian, are at present found only in southwestern Pennsylvania and adjacent parts of Ohio and West Virginia. The compressive forces from the southeast which brought about the Appalachian revolution that terminated the Paleozoic era in eastern North America, had already become active at that time. The shifting of the zone of maximum deposition toward the west, therefore, may have been responsible for the small west component of the regional dip of the surface formations in the Bradford district. If this interpretation is correct it follows that the gentle folds of the Bradford district were superimposed upon an already present regional tilt.

JOINTING AND FAULTING

The outcropping stratified rocks of the Bradford district are intersected by a series of nearly vertical fractures or joints which fall mostly into two groups or sets, namely, strike joints, which are approximately paralled to

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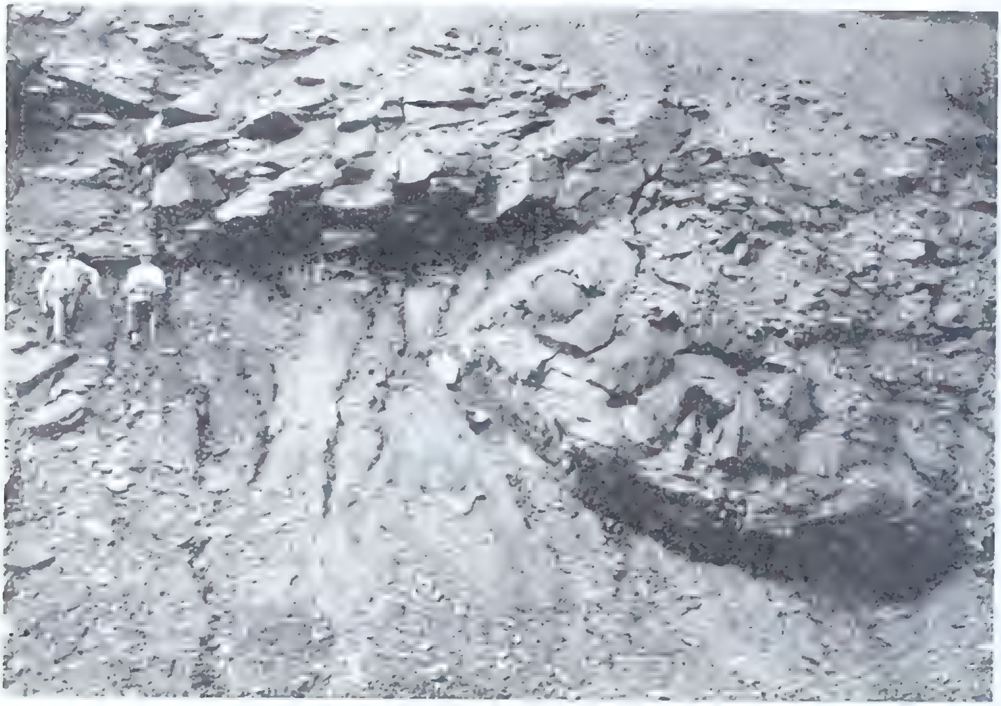
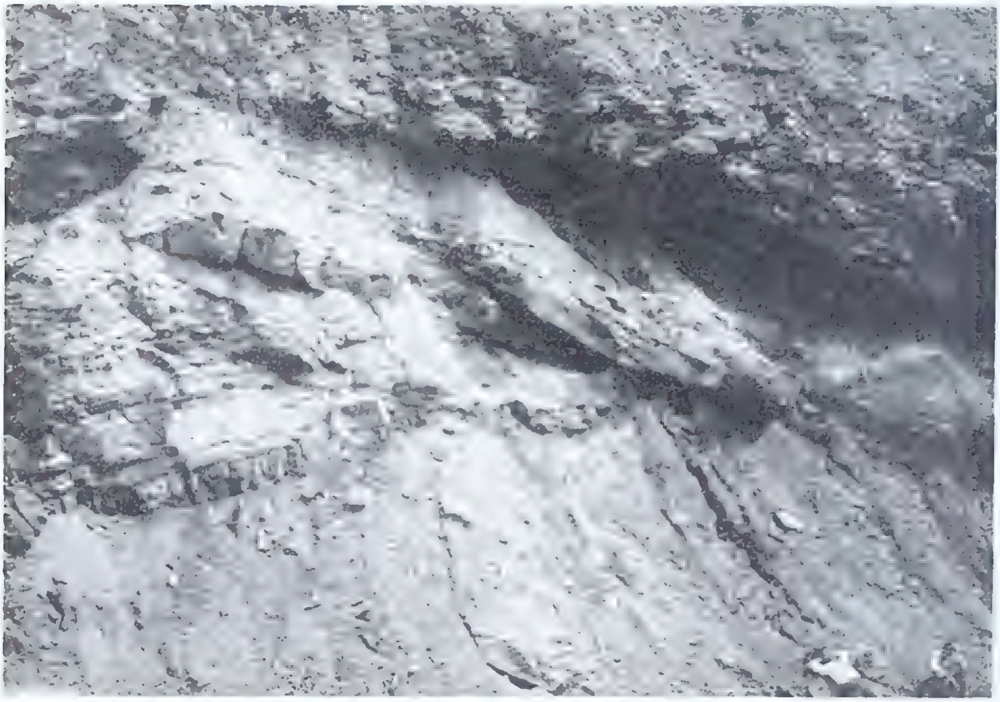
[13] R. E. Sherrill, idem.
S. H. Cathcart, Geologic structure of northwest Pennsylvania has deep sand possibilities of gas and oil: The Oil and Gas Journal, Dec. 20, 1934, p. 58.

[14] Paul H. Price, The Appalachian structural front: Jour. Geology, vol. XXXIX, 1931, pp. 40 and 43.



A. Small thrust fault in lower Pennsylvanian strata, Buffalo, Rochester and Pittsburgh railroad cut near McKean-Elk County line south of Hutchins, west side.



B. Same, east side.

the strike of the beds, and dip joints, which are approximately parallel to the direction of dip. The strikes of these joints at a number of widely separated localities are shown on Plate C. They were measured on outcrops of strata ranging from sandstones and conglomerates to sandy shales and coal beds. It will be noted that the direction of the joints changes in going from the northeastern to southwestern part of the district in a manner corresponding to the change in trend of the axes of the folds. Wedel[15] has observed a similar change in the strike of the joints in the Devonian strata of south-central New York.

Miss Sheldon, who made a detailed study of joints similar to those of the Bradford district in the Ithaca region of New York, came to the conclusion that the master joints, namely, the strike and dip joints, were formed in the earlier part of the period of folding. She found that subjecting models constructed of paraffin and resin to pressure gave fine cracks at right angles to the pressure and nearly parallel to the pressure. By analogy, the horizontal pressure that was applied to the strata during the Apalachian Revolution should have formed cracks having directions like the observed joints.[16] Bucher, on the other hand, in a discussion of the observations made by Miss Sheldon, concludes that the formation of these joint systems was independent of the folding and followed it and that the joints represent planes of shearing produced by compression in a N.E.-S.W. direction under general conditions of torsion[17] Nevin has suggested that there may be a similarity in the development of joint systems in batholiths, as brought out by the work of Cloos, and in sedimentary rocks. In these two dissimilar types of rocks the vertical joints appear to be at approximately right angles to and paralled with the direction of the regional stresses.[18] As Wedel has pointed out, the field evidence seems to show that the joints are approximately either parallel with or at right angles to the folding and do not lie in planes of maximum shear although they may have been formed by shearing stresses.[19]

Although joints, as a rule, are closed in depth, they represent zones of weakness in the rock. On the outcrop they are enlarged by atmospheric agents, and both mechanical and chemical weathering of the rock are accelerated along them. This is well illustrated by the surface of the Olean conglomerate exposed at Rock City, south of Olean. (See pl. 7, B).

No direct evidence of faulting has been observed within the limits of the Bradford district. Occasional boulders of sandstone encountered on talus slopes, however, show slickensided surfaces, suggesting that at least slight movements occurred along some of the joint surfaces when the regional stresses produced the gentle folding and jointing in the strata.

Not far south of the Bradford district, south of Hutchins near the McKean-Elk County line in a prominent cut along the Buffalo, Rochester, and Pittsburgh railroad, a small thrust fault is exposed intersecting lower Pennsylvanian strata. This is shown in Plate 13. It is not likely that this fault possesses any great lateral extent. It probably represents a local adjustment in a comparatively incompetent thin-bedded shale, coal, and sandstone horizon, that took place during the general uplift of the region.

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[15] A. A. Wedel, Geologic structure of the Devonian strata of south-central New York: New York State Mus. Bull. 294, 1932, p. 30.

[16] Pearl Sheldon, Some observations and experiments on Joint Planes: Jour. Geology, vol. XX, 1912, pp. 176-177.

[17] Walter H. Bucher, The mechanical interpretation of joints: Jour. Geology, vol. XXVIII, 1920, p. 724.

[18] C. M. Nevin, Principles of Structural Geology, New York, 1931, pp. 150-152.

[19] A. A. Wedel, Geologic structure of the Devonian strata of south-central New York: New York State Mus. Bull. 294, 1932, pp. 33-34.

LOCAL

SURFACE STRUCTURE

The outcropping strata in the Bradford district contain no well-defined key horizons that can readily be traced over the entire area. This, in conjunction with an absence of abundant outcrops, makes mapping of the surface structure difficult. Also an unconformity exists at the base of the Olean which further complicates the problem. The old erosion surface upon which the Olean was deposited was irregular. As a result, the base of the Olean in some places is anywhere from 20 to 60 feet lower than a nearby outcrop of the Knapp. Besides being an irregular surface, the unconformity also bevels the underlying strata which had already been tilted slightly in a southerly direction following the deposition of the Knapp and preceding the deposition of the Olean.

The surface structure map, drawn on the base of the Olean, using a contour interval of 50 feet, which is shown in Plate C, therefore, is somewhat generalized. Since the surface on which it is drawn was not a true plane when the Olean was deposited, it probably deviates somewhat from representing a strictly structural map. However, two anticlinal folds with accompanying synclines, merging at the north, stand out clearly enough to justify one in concluding that they are of tectonic origin and were developed in post-Pottsville time. Their trends are parallel to those of the foreland folds already described. Reference to Figure 6 shows that they occur along the northwestern margin of this belt of folds and no doubt are part of it.

SUBSURFACE STRUCTURE

A detailed structure map of the Bradford district has been prepared which shows the elevation of the top of the Bradford Third sand above sea-level by means of contours. A 10-foot interval has been used. This map is shown in Plate A. Another map of the district, drawn to the same scale as that of Plate C, has been included so that the subsurface structure on the Bradford Third sand can readily be compared with the surface structure. This is shown in Plate E. Only the 50-foot contours have been drawn on this map.

The major structural features of the Bradford Third sand in the Bradford district are two asymmetrical anticlines trending northeast and southwest, plunging southwest, and converging on the northeast in a broad dome. The anticlines have broad tops with gentle dips toward the northwest and considerably steeper dips toward the southeast. Sherrill has shown that this asymmetrical character is typical of the northern Appalachian foreland folds in general. The anticlines are steeper on the flank facing the more intensely deformed mountains.[20]

By comparing Plates C and E it is seen that the major structural features developed on the erosion surface at the base of the Olean are essentially parallel to those developed on the top of the Bradford Third sand. This indicates that the present structural features of the latter were also developed in post-Pottsville time.

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[20] R. E. Sherrill, Symmetry of Northern Appalachian foreland folds: Jour. Geology, vol. XLII, 1934, p. 247.

The more detailed structural map shown in Plate A reveals minor configurations on the upper surface of the Bradford Third sand which probably are due largely to depositional conditions and differential compaction. Such features would be still more conspicuous if a smaller contour interval had been used.

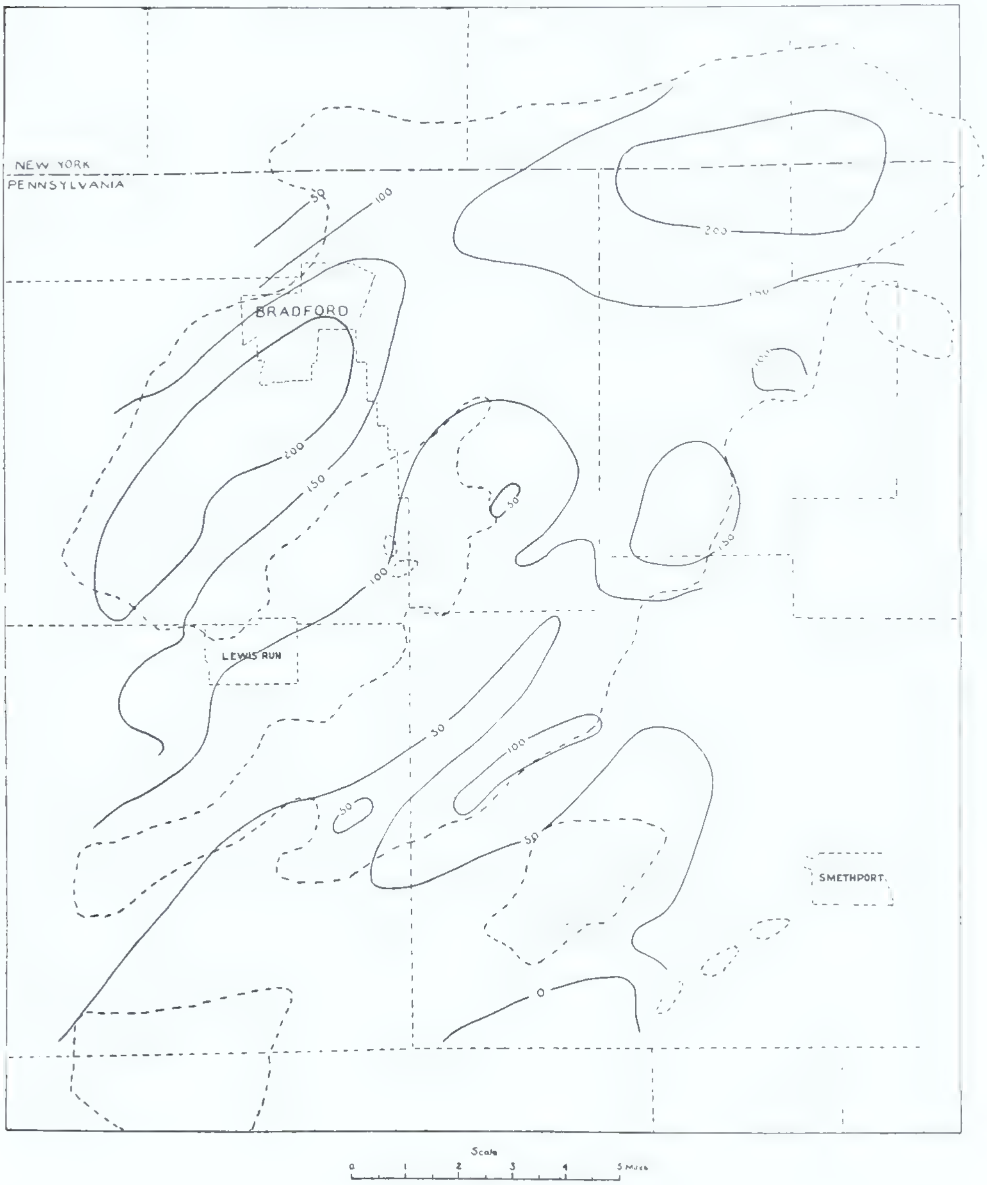

FIGURE 7. **Configuration on the top of the Bradford Third sand at the beginning of Pottsville time.**

In Figure 7 an attempt has been made to show the configuration of the top of the Bradford Third sand as it appeared at the beginning of Pottsville time. In constructing this map it was assumed that the erosion surface on which the Olean was deposited represented a level plain at that time. As has been pointed out previously, this is not exactly true. The map can, therefore, be considered to represent only an approximation. A 50-foot contour interval has been used. The datum plane is an imaginary one. This map indicates that the trend of the Bradford anticline, the major structural feature of the district, was already foreshadowed by two broad elongated domes on the Bradford Third sand at the beginning of Pottsville time. To what extent this shape of the top of the Bradford Third sand was due to warping during the uplift that preceded the deposition of the Pottsville beds has not been established. The features shown may have been due in part at least to uneven deposition and differential compaction.

HISTORICAL GEOLOGY

PALEOZOIC ERA

Throughout much of the Paleozoic era that area included in the Bradford district was covered by an arm of the sea that occupied the Appalachian geosyncline, a long and relatively narrow trough that extended with varying outlines during different epochs of Paleozoic time across the eastern part of the North American continent from the Gulf of Mexico to the Gulf of St. Lawrence. On the east this sea was bordered by a great continental land mass, Appalachia, composed of ancient metamorphic and igneous rocks. This land mass probably included part of southeastern Pennsylvania and extended eastward beyond the present shore line to the edge of the continental shelf and possibly beyond. On the west and northwest of the geosyncline the adjacent land areas remained low-lying throughout most of Paleozoic time and at intervals, when the seas spread beyond the confines of the trough, were submerged beneath shallow waters.

ORDOVICIAN PERIOD

The oldest rocks thus far penetrated by the drill in the Bradford district, the Queenston red shales, were deposited either during the latter part of the Ordovician or at the beginning of the Silurian period. As previously mentioned, there is still some difference of opinion among geologists as to which period these beds belong.

Toward the latter part of Ordovician time the northern part of Appalachia was affected by an orogenic disturbance which culminated in a chain of mountains that extended from central Newfoundland through Nova Scotia, New Brunswick, and the New England States at least as far south as New Jersey. This has been called the Taconic disturbance because the early Paleozoic rocks now exposed in the Taconic Range of western Massachusetts were intensely folded at this time.

The Queenston red shales and their equivalents, the Juniata beds of central Pennsylvania, represent part of a vast series of deltas that formed on the west side of these rising mountains. The absence of marine fossils would seem to indicate that they were deposited largely under subaerial conditions. Westward they interfinger with the marine gray fossiliferous shales of the Richmond formation.

SILURIAN PERIOD

Subaerial sedimentation continued in the Bradford region during early Silurian time. The streams, flowing in a northwesterly direction from the recently elevated Taconic mountains, brought to the area abundant sandy sediments which formed the Medina sandstones.

As the mountains to the east were gradually worn down and the Appalachian geosyncline continued to subside, marine waters again invaded the region. The clastic materials washed into the shallow sea by the streams became finer and gave rise to the shales of the Clinton group. In time the land mass of Appalachia was reduced to such an extent that it no longer contributed appreciable amounts of clastic materials, and the calcareous deposits comprising the Lockport dolomite were laid down in the resulting clear waters.

After the deposition of the Lockport dolomite, a considerable portion of the northern Appalachian geosyncline became a land-locked basin separated from the open sea by a bar or barrier of some sort. Desert conditions prevailed over this region at the time. The argillaceous and magnesian limestones, calcareous and dolomitic shales, and clays of the Salina group were deposited in this basin. Streams, draining adjacent low-lying areas of previously elevated shales and limestones, furnished the necessary fine argillaceous and limey muds. The anhydrite and salt beds, which constitute part of the Salina sediments, were deposited through evaporation of saline waters under desert conditions in extensive shallow lakes which covered large parts of the basin. The salt itself probably was derived from several sources. Part of it may have come from the occasional influx of additional sea water over the bar or through a narrow channel in the barrier which separated the basin from the open sea. Streams draining areas of recently elevated marine sediments around the margins of the basin may also have contributed some of it. Evaporation apparently never went to completion as no commercial potash salt deposits have as yet been discovered in these beds. There were, on the other hand, a number of incomplete cycles interrupted by influx of sea and river waters. The Salina type of sedimentation was terminated by the establishment of an open connection with the sea again. The deposition of a magnesian limestone marked the close of the Silurian period in the Bradford region. No uplift occurred in eastern North America at this time.

DEVONIAN PERIOD

At the beginning of Devonian time the land mass of Appalachia stood only a short distance above sea-level and supplied relatively little in the way of clastic sediments to the adjacent Appalachian trough. This was occupied by a narrow arm of the sea in which the limestones and calcareous shales of the Helderberg group accumulated. The Bradford district is near the northwestern shore line of this ancient strait.

Over the low-lying landmass to the east, chemical decomposition of the exposed rocks was an important factor in the weathering process, in contrast to mere mechanical disintegration of the rocks. All the silicate minerals accompanying the quartz in the rocks were thoroughly altered and disintegrated into soft, readily pulverized secondary products, leaving the quartz grains free. In time, winds probably separated and blew away much of the fine material. Running water no doubt aided in the sorting. As a result, a sandy mantle accumulated over the low lands of Appalachia. A slight uplift of the land mass caused the streams to shift the sand to the adjacent shallow Appalachian sea, forming the Oriskany sandstone. The thickest beds of sand were laid down at the mouths of the larger streams in the forms of deltas, while the fine material was carried farther out into the sea. Wave action and shore currents undoubtedly also played a part in the further separation of the coarse from the fine material and its distribution over the sea floor. In the areas beyond and between the deltas some limestone accumulated. The Oriskany sandstone was deposited over a somewhat greater area than the Helderberg limestones and calcareous shales.

After the deposition of the Oriskany sandstone, further subsidence caused the seas to spread over a considerably wider area. The adjacent land areas remained low-lying so that the succeeding sediments consisted of a rather pure limestone, the Onondaga, remarkably widespread and uniform in its character.

Following the deposition of the Onondaga limestone, the land mass of Appalachia again started to rise slowly while gentle subsidence continued in the trough to the west which was occupied by a shallow arm of the sea. The shales and associated rocks of the Hamilton group were next laid down. These are coarsest toward the east in the direction of the old land mass and become progressively finer in texture westward so that in the Bradford area they consist almost entirely of dark to black shales with occasional thin interbedded limestone lenses. At times the waters over considerable areas apparently were unaffected by waves or other currents. Over these stagnant areas muds rich in organic debris accumulated which gave rise to the black shales so characteristic of much of the Hamilton, particularly the lower portion, in the district.

Over much of central New York and north-central Pennsylvania a prominent bed of limestone, the Tully, was deposited on the Hamilton shales. This limestone has its greatest development in north-central Pennsylvania but its edges reach as far west as the Bradford district.

Beginning in Hamilton time and reaching its climax at the close of the Devonian an uplift again affected Appalachia. This has been called the Acadian disturbance because, in the Acadian region of eastern Canada, Devonian as well as older sediments were strongly folded and disturbed by much igneous activity at this time. It inaugurated the deposition of a great series of delta deposits along the western flanks of Appalachia that extended all the way from the Catskill region of New York to the southern Appalachians. The landward portions of this series of delta deposits were laid down largely under subaerial conditions. A semiarid climate probably prevailed so that the sediments were thoroughly oxidized during the dry season as their color is dominantly red. They constitute the so-called Catskill red beds of the Middle and Upper Devonian of eastern North America.

The gray fossiliferous shales, sandy shales, and sandstones of the Hamilton, Portage, Chemung, and Conewango groups are the western marine equivalents of these continental red beds. In following each stratigraphic horizon westward, the change from red to gray marks the approximate location of the shoreline at that time. Interfingering of the marine and nonmarine beds indicates wide fluctuations of the shoreline east and west, as subsidence and filling failed to keep pace. The general westward shift of the red beds shows, however, that the deltas were being extended in that direction with the passing of time. Over relatively broad, somewhat deeper areas of stagnant waters beyond the margins of the growing deltas, the black muds rich in organic debris, that gave rise to the black shales of the Genesee formation as well as those of the Portage and Chemung groups, accumulated.

The red type of sedimentation did not reach the Bradford district until late in Upper Devonian time when the Cattaraugus red beds were laid down. These extend only a short distance beyond the western limits of the district. The Cattaraugus formation in the Bradford district contains several horizons rich in marine fossils and is succeeded by the gray marine beds comprising the Oswayo formation, which are generally conceded to be of Devonian age. Marine conditions apparently prevailed over the Bradford region to the very close of the Devonian period.

MISSISSIPPIAN PERIOD

Whether any strata of Mississippian age are present in the Bradford district is still a moot question among stratigraphers. In this area there is no evidence of an appreciable erosional unconformity between the Oswayo shales and the overlying Knapp beds. The fossil fauna of the latter, however, possesses a decidedly Mississippian aspect.

The occurrence of a marine conglomerate, composed of discoidal quartz and occasional jasper pebbles at the base of the Knapp in the western part of the district, that grades into sandstones and sandy shales eastward, would seem to indicate that the area was near the northwestern shore of a narrow arm of a sea which extended over the area during earliest Mississippian time and to the southwest connected with the main embayment which occupied the Mississippi Valley region. The fact that occasional jasper pebbles were present in this conglomerate has led to the suggestion that the Lake Superior region, where outcrops of jaspilite occur, was the source of the material. The shape of the pebbles is probably due to two factors. They may have been derived from comparatively narrow quartz veinlets in the metamorphic rocks of the region from which the sediments came so that the quartz fragments were flat at the start. After the streams had transported them to the sea they probably were washed to and fro by the waves for a considerable time before finally coming to rest. This would also have had a tendency to give them a discoidal rather than an ovoid or ellipsoidal shape.

It has been pointed out that the Knapp conglomerate and overlying marine sandy shales and sandstones of the Bradford district are all older than the strata composing the so-called Pocono and Mauch Chunk formations of Mississippian age to the south. Just how long sedimentation continued and what thickness of strata was laid down in the district during Mississippian time after the deposition of the Knapp beds is not known. These later beds were removed by erosion following the uplift that marked the close of the Mississippian period.

This uplift was accompanied by a tilting of the strata in a southerly direction as the erosion surface which developed during the succeeding interval beveled successively older and older strata in a northerly direction. At Guffey, in the southern part of the district, the interval between the base of the Knapp and the base of the Olean is 187 feet, while at the village of Knapp Creek in the northern part of the district it is only 65 feet, the decrease, as has been shown, being due to the truncation of the higher beds immediately below the Olean conglomerate by the erosion surface.

PENNSYLVANIAN PERIOD

At the beginning of the Pennsylvanian period the Bradford area stood above sea-level and was undergoing erosion which no doubt removed considerable thicknesses of Mississippian strata. By the time sedimentation was resumed, late in the Pottsville epoch, a more or less uneven erosional surface had developed.

The Pottsville strata of the Bradford district contain no marine fossils. Apparently they were deposited under subaerial and fresh water conditions. The conglomerate and sandstones comprising the Olean member represent alluvial fans which were spread out over the region by streams flowing from a recently elevated area lying to the north and northeast. The quartz pebbles of this conglomerate, for the most part, are ovoid or ellipsoidal rather than discoidal. Jasper is absent. They apparently came from a different source than those of the Knapp.

The next succeeding beds, the Sharon shales, were deposited by more sluggish streams. Locally, swampy conditions prevailed, as witnessed by the occasional presence of a thin coal bed in these shales. After the deposition of the Sharon shales, the streams were again rejuvenated by further uplift and brought coarser sediments to the region, resulting in the deposition of the Connoquenessing sandstone. Overlying this sandstone are the Mercer shales. These were deposited under conditions very similar to those which prevailed at the time the Sharon shales were laid down. Somewhat larger swamps came into existence at several intervals. These were of sufficient duration to provide enough peat for at least one coal bed of minable thickness over local areas.

The Mercer member of the Pottsville represents the youngest horizon of Pennsylvanian age that now remains in the Bradford district. The total thickness of Pennsylvanian and possibly Permian sediments that accumulated over the region and has since been removed by erosion, is uncertain. If the vertical joint systems, which intersect the youngest consolidated strata remaining in the district, were the result of regional stresses acting on brittle rocks under conditions where lateral relief was easier than upward relief, as suggested by Nevin, this thickness must have been considerable.

Toward the close of the Paleozoic era a great mountain-making movement set in, known as the Appalachian revolution, during which the old land mass of Appalachia was thrust northwestward against the thick series of sediments that had accumulated in the Appalachian geosyncline, crumpling these into a series of folds that extended from Nova Scotia to Alabama. The forces which brought about this deformation came from the southeast. The folding was most intense over that portion of the geosyncline comprising the eastern limb. Westward it became less and less severe. The Bradford district is near the northwestern or outermost margin of the belt of foreland folds lying west of the closely folded belt.

MESOZOIC ERA

At the beginning of the Mesozoic era the Bradford area was part of a broad plateau bordered on the southeast by a great mountain chain, the ancestral Appalachian Mountains. Throughout Mesozoic time the agents of weathering and erosion were active on its surface, gradually wearing it down to sea-level.

CENOZOIC ERA

Denudation continued well on into Tertiary time. To what extent the region was affected by epeirogenic movements involving either uplift or subsidence during this long interval, is not known as the subsequent erosion has obscured and obliterated all evidence of their occurrence. By the middle of Tertiary time the whole region had been worn down to a nearly level plain lying close to sea-level. About this time the Bradford area was again raised a few thousand feet above sea-level and the rejuvenated streams that flowed across its surface began to carve out the present topographic features.

During the Pleistocene epoch of the Quaternary period the glaciers which accumulated over the northern half of the North American continent advanced as far south as Salamanca. The Allegheny River was not able to carry away all the debris which was dumped into it by the melting ice along the glacier front and commenced to fill its valley with sand and gravel, thereby elevating its flood plain until this reached the level of the present high terraces between 1480 and 1500 feet. As a result, tributaries entering from the south became blocked. At first they deposited small amounts of sand and gravel in their channels also, but since their loads of debris were small, as compared with those dumped into the Allegheny by the glacier, they could not build up their beds as fast as the Allegheny and consequently ceased to flow and became lakes. Deposition continued in these lakes until in the case of the Tunungwant valley below Foster Brook, the old channel was buried to a depth of nearly 250 feet. The water in this lake at the maximum stage probably reached a level close to the position of the present 1500-foot contour. A uniform level was not maintained long enough, however, to develop a well-defined terrace along its shores.

The advent of the glaciers forced Allegheny River to change its course. The old river turned northwestward in the vicinity of Steamburg, New York, and emptied into a stream that occupied a valley now covered by the waters of Lake Erie. In the vicinity of Steamburg it was joined by a tributary entering from the south which included the present Kinzua Creek. When the advancing ice sheet blocked the northwestward outlet of the old Upper Allegheny River, its waters rose until they overflowed a low divide south of Kinzua in the vicinity of Big Bend and the present southward course of the river was established. As a result, water now draining into Kinzua Creek in the vicinity of Bingham and Simpson flows only 29 miles to join the present Allegheny River at Kinzua, while water draining into Tunungwant Creek in the same vicinity flows 57 miles to reach the same point. Before the advent of the glaciers the water entering the Kinzua drainage flowed 48 miles to reach the point where Kinzua Creek formerly joined Allegheny River in the vicinity of Steamburg, while that which entered the Tunungwant flowed only 38 miles to reach the same point.

After the melting of the glaciers at the close of the Pleistocene epoch, the Allegheny began to remove the material deposited along its course. The lakes along the tributaries were drained. Only sufficient time has elapsed, however, to permit the tributary streams to cut comparatively shallow channels, frequently not much more than five feet, into the alluvial deposits that had accumulated in their valleys.

PETROLEUM AND NATURAL GAS

Certain geological features are common to all regions in which commercial deposits of petroleum and natural hydrocarbon gases occur. Such deposits are always found associated with sedimentary rocks. Small amounts of petroleum are occasionally found along fractures and other openings in igneous and metamorphic rocks and in a few fields altered igneous rocks and volcanic breccias and tuffs are the reservoir rocks, but in all these cases the igneous or metamorphic rocks occur rather close to sedimentary rocks and the oil has no doubt been derived from organic debris entombed in the latter.

Petroleum invariably is associated with sedimentary rocks of marine origin. Sediments deposited under continental conditions, either subaerial or fresh-water, may occur interstratified with the marine beds and may even constitute the reservoir rocks, but where petroleum is present in commercial quantities a large part of the sedimentary series is always found to be of marine origin. Most commercial deposits of natural hydrocarbon gases are likewise associated with sedimentary strata of marine origin, but cases are known where natural gas, not associated with oil, has been found that has apparently been derived from vegetable debris deposited under fresh-water conditions, as, for example, the sporadic occurrences of commercial quantities of gas in strata immediately above the Pittsburgh coal in southwestern Greene County, Pennsylvania, and adjacent portions of West Virginia.

Through such agencies as lateral pressure accompanying orogenic movements, downward pressure exerted by the overlying load of sediments, and heat encountered by deep burial, frequently accompanied by the action of liquids, vapors and gases, sedimentary rocks, such as sandstones, shales and limestones become altered or metamorphosed into quartzites, slates, schists, and marbles. Commercial oil and gas deposits are not encountered in metamorphic rocks. In nature all gradations between the sedimentary rocks and their intensely metamorphosed equivalents are found. Inasmuch as oil and gas deposits occur in the former and not in the latter, somewhere in between there must be a certain degree of metamorphism which constitutes an extinction zone for these deposits.

Of the sedimentary rocks, coals are particularly susceptible to metamorphic alteration. The percentage of fixed carbon computed on a pure coal basis in the case of bituminous and higher rank coals constitutes an excellent criterion for judging the degree of metamorphism that the associated strata have undergone, the fixed carbon increasing with the intensity of the metamorphism. White has pointed out that the zone between 62 and 65 per cent of fixed carbon may be considered the extinction zone for the occurrence of commercial deposits of petroleum. Natural gas fields extend into areas of more advanced metamorphism[21]. In the Bradford district, the coal bed in the Mercer member of the Pottsville, mined at Lafayette Cross-roads, has a fixed carbon content of 57.4 percent, computed on a pure coal basis.

Inasmuch as the intensity of metamorphism normally increases with depth, the oil and gas horizons below the coal measures may be expected to have undergone a somewhat greater degree of metamorphism than the latter, the amount depending not only upon the depth but also on any effects that may have resulted from pre-Pennsylvanian earth movements.

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[21] David White, Metamorphism of organic sediments and derived oils: Bull. American Assoc. of Petroleum Geologists, vol. 19, 1935, p. 592.

From the above discussion it is seen that another condition necessary for the occurrence of oil or gas deposits in a particular area is that the sedimentary rocks have not undergone too great a degree of metamorphism.

In a region underlaid by marine sedimentary rocks that have not been too greatly metamorphosed, three further prerequisites are necessary for the occurrence of commercial deposits of petroleum and natural hydrocarbon gases.

Practically all petroleum geologists are now agreed that petroleum and the associated natural hydrocarbon gases have been derived from organic matter of vegetable or animal origin, deposited in sediments. Oil and gas deposits can have developed only in regions where source beds contained sufficient organic debris suitable for the formation of these hydrocarbons.

After the generation of the liquid and gaseous hydrocarbons from the organic debris started, space was required to permit them to accumulate in commercial quantities. There must be interstratified in the sedimentary series, therefore, certain rocks, known as reservoir rocks, that possess a sufficient volume of connected openings or pore spaces to act as containers. These reservoir rocks must be overlain by relatively impervious beds so that after the oil and gas accumulated they could not escape to the surface and be lost.

At the start the pore spaces in the reservoir rocks were occupied by water, in most instances salt water. Globules of oil and bubbles of gas entered the pores and replaced part of the water. The fluids were not in a static condition. Lateral and vertical migration occurred. In order to permit a segregation of the gas and oil from the associated water, the presence of certain structural features in the reservoir rock, such, for example, as an anticlinal fold or a dome, were necessary to act as a trap for the oil and gas.

All the above geological features must be taken into consideration by the petroleum geologist in connection with the search for new oil and gas pools. After a new pool has been discovered, an understanding of the characteristics of the reservoir rock and the structural relations is essential to its proper development. Detailed information on the nature of the reservoir rock is also essential at the start in order to utilize intelligently the energy inherent in the pool to the best advantage in connection with the production of oil and later on to apply secondary recovery methods, such as repressuring with natural gas or air or flooding with water.

RESERVOIR ROCKS

All of the oil and gas production in the Bradford district to date has come from sandstones of Upper Devonian age. From the standpoint of oil production, only one horizon, the Bradford Third sand, is of major importance. Locally, over small areas, however, some oil and gas have been obtained from the Chipmunk, Bradford Second, Harrisburg Run, Lewis Run, Kane and Haskell sands.

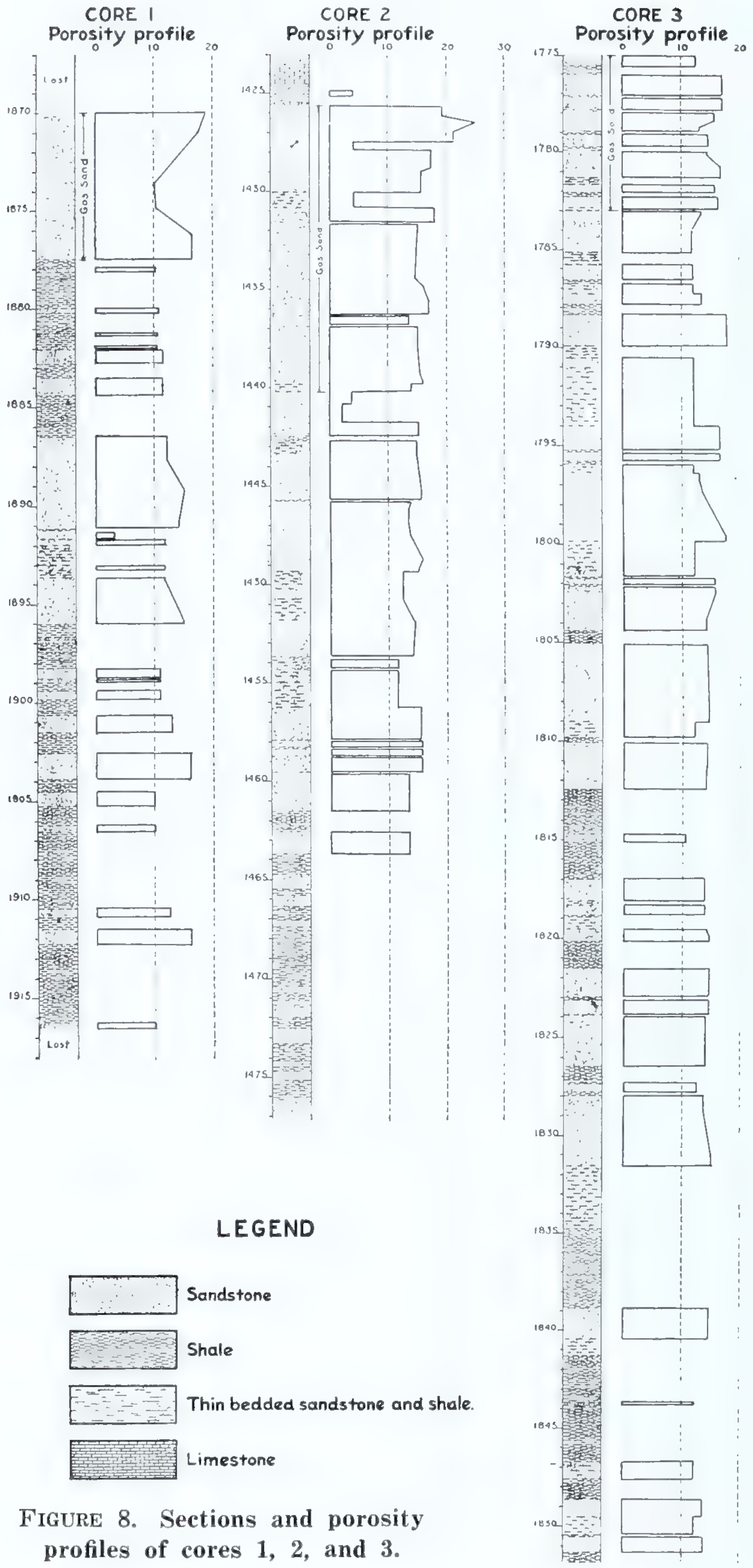

FIGURE 8. Sections and porosity profiles of cores 1, 2, and 3.

BRADFORD THIRD SAND

The Bradford Third sand, although exhibiting a remarkable continuity and a considerable degree of homogeneity over 84,000 acres of proved territory, is by no means uniform in the entire area of the field. Wide variations in total thickness and number and thickness of shale partings occur in many places between adjacent properties and even adjacent wells. Cross-bedding, however, appears to be absent. Studies of cores indicate variations in porosity, uniformity and actual size of grains, character and amount of cementing material, permeability, and oil content, both vertically and laterally, in the sand. In general, however, these variations are not as great as in some of the other oil sands of Pennsylvania, as, for example, those of the Venango group that have been studied in detail by the writer[22].

Detailed sections of the Bradford Third sand, as revealed by cores, from 21 wells, widely scattered in the Bradford district, are given in Table 6 and are shown graphically by the usual conventional symbols in Figures 8 to 14, inclusive. Their locations are indicated on Plate E.

Table 6. Sections of Bradford Third Sand from 21 wells in the Bradford District

Section of Core 1

Thickness feet	Description of strata	Depth to top feet
	Top of Bradford Sand	1867.00
3.00	Lost	1867.00
2.10	Sandstone, moderately hard medium-grained grayish-brown	1870.00
2.90	Sandstone, hard fine-grained dark chocolate-brown	1872.10
2.50	Sandstone, moderately hard medium-grained grayish-brown, with occasional minute quartz pebbles up to 2 mm. in diameter	1875.00
	Bottom of Gas sand	
.40	Shale with thin seams of very hard fine-grained brown sandstone	1877.50
.20	Sandstone, hard fine-grained chocolate-brown	1877.90
1.90	Shale with some thin seams of hard chocolate-brown sandstone	1878.10
.20	Sandstone, hard fine-grained chocolate-brown	1880.00
1.00	Shale	1880.20
.10	Sandstone, hard fine-grained chocolate-brown	1881.20
.50	Shale	1881.30
.10	Sandstone, hard fine-grained chocolate-brown	1881.80
.10	Shale	1881.90
.70	Sandstone, hard fine-grained chocolate-brown	1882.00
.80	Shale	1882.70
.80	Sandstone, hard fine-grained chocolate-brown	1883.50
2.10	Shale	1884.30
4.70	Sandstone, moderately hard fine-grained chocolate-brown	1886.40
.10	Shale	1891.10
.10	Sandstone, hard fine-grained chocolate-brown	1891.20
.40	Sandstone, very hard very fine grained light bluish-gray argillaceous	1891.30
.30	Sandstone, hard fine-grained chocolate-brown	1891.70
1.00	Sandstone, very hard fine-grained chocolate-brown, with interbedded hard bluish-gray sandstone	1892.00
.20	Sandstone, hard fine-grained chocolate-brown	1893.00
.40	Sandstone, hard fine-grained light bluish-gray, argillaceous	1893.20
2.40	Sandstone, moderately hard fine-grained chocolate-brown	1893.60

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[22] Chas. R. Fettke, Core studies of the Second sand of the Venango group from Oil City, Pa.; Petroleum Development and Technology in 1926: Trans., Am. Inst. Min. Eng., 1927, pp. 219-230.

Ten years' application of compressed air at Hamilton Corners, Pa., with core studies of the producing sand. Petroleum Development and Technology in 1927, Trans., Am. Inst. Min. Eng., vol. 77, 1928, pp. 303-316.

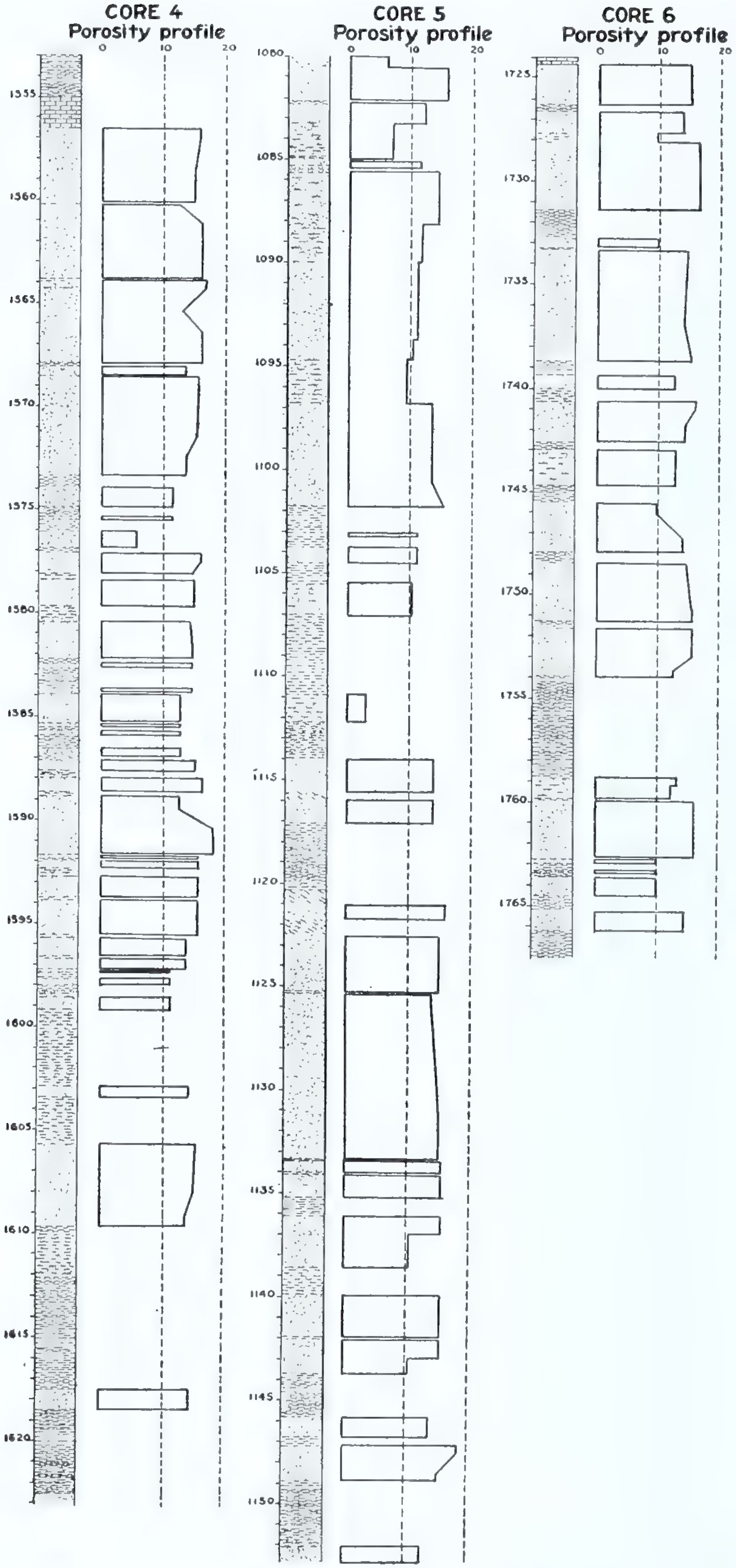


FIGURE 9. Sections and porosity profiles of cores 4, 5, and 6.

Core 1 Continued

Thickness feet	Description of strata	Depth to top feet
.60	Shale	1896.00
.05	Sandstone, hard fine-grained chocolate-brown	1896.60
.18	Shale	1896.65
.06	Sandstone, hard fine-grained chocolate-brown	1896.83
1.50	Shale with a few thin seams of sandstone, hard fine-grained chocolate-brown	1896.89
.48	Sandstone, hard fine-grained chocolate-brown	1898.39
.12	Shale	1898.87
.12	Sandstone, hard fine-grained chocolate-brown	1898.99
.35	Shale	1899.11
.35	Sandstone, hard fine-grained chocolate-brown	1899.46
.84	Shale with a few thin seams of sandstone, hard fine-grained chocolate-brown	1899.81
.85	Sandstone, moderately hard fine-grained chocolate-brown	1900.65
1.00	Shale with a few thin seams of hard fine-grained chocolate-brown sandstone	1901.50
1.35	Sandstone, moderately hard fine-grained chocolate-brown	1902.50
.60	Shale	1903.85
.77	Sandstone, hard fine-grained chocolate-brown	1904.45
.94	Shale	1905.22
.34	Sandstone, hard fine-grained chocolate-brown	1906.16
3.90	Shale with a few thin seams of hard chocolate-brown sandstone	1906.50
.50	Sandstone, hard fine-grained grayish-brown	1910.40
.60	Shale	1910.90
.17	Sandstone, hard fine-grained grayish-brown with numerous thin shale seams	1911.50
.60	Sandstone, moderately hard fine-grained chocolate-brown	1911.67
4.00	Shale with some thin seams of hard fine-grained chocolate-brown sandstone	1912.27
.23	Sandstone, hard fine-grained very dark chocolate-brown	1916.27 1916.27

Section of Core 2

.30	Shale	1423.00
1.20	Limestone, fossiliferous	1423.30
.33	Shale	1424.50
.25	Sandstone, very hard fine-grained light bluish-gray	1424.83
.25	Shale	1425.08
	Top of Bradford Sand	1425.33
.15	Sandstone, hard fine-grained brown	1425.33
.10	Shale	1425.48
1.90	Sandstone, moderately friable fine-grained chocolate-brown	1425.58
.10	Sandstone, very hard fine-grained light-gray	1427.48
.21	Sandstone, hard fine-grained chocolate-brown	1427.58
.10	Sandstone, very hard fine-grained light-gray	1427.79
2.15	Sandstone, moderately friable fine-grained chocolate-brown	1427.89
.82	Sandstone, hard fine-grained chocolate-brown with numerous thin shale seams	1430.04
.72	Sandstone, moderately hard fine-grained chocolate-brown	1430.86
.10	Shale	1431.58
4.65	Sandstone, moderately friable fine-grained chocolate-brown	1431.68
.05	Shale	1436.33
.54	Sandstone, moderately hard fine-grained chocolate-brown	1436.38
.05	Shale	1436.92
2.92	Sandstone, moderately hard fine-grained chocolate-brown	1436.97
.39	Sandstone, moderately hard fine-grained chocolate-brown, with numerous thin shale seams and lenses	1439.89
.58	Sandstone, very hard fine-grained light brownish-gray fossiliferous	1440.28
.96	Sandstone, very hard fine-grained light greenish-gray fossiliferous	1440.86
	Top of oil pay	1441.82
.77	Sandstone, moderately hard fine-grained chocolate-brown	1441.82
.20	Sandy shale	1442.59

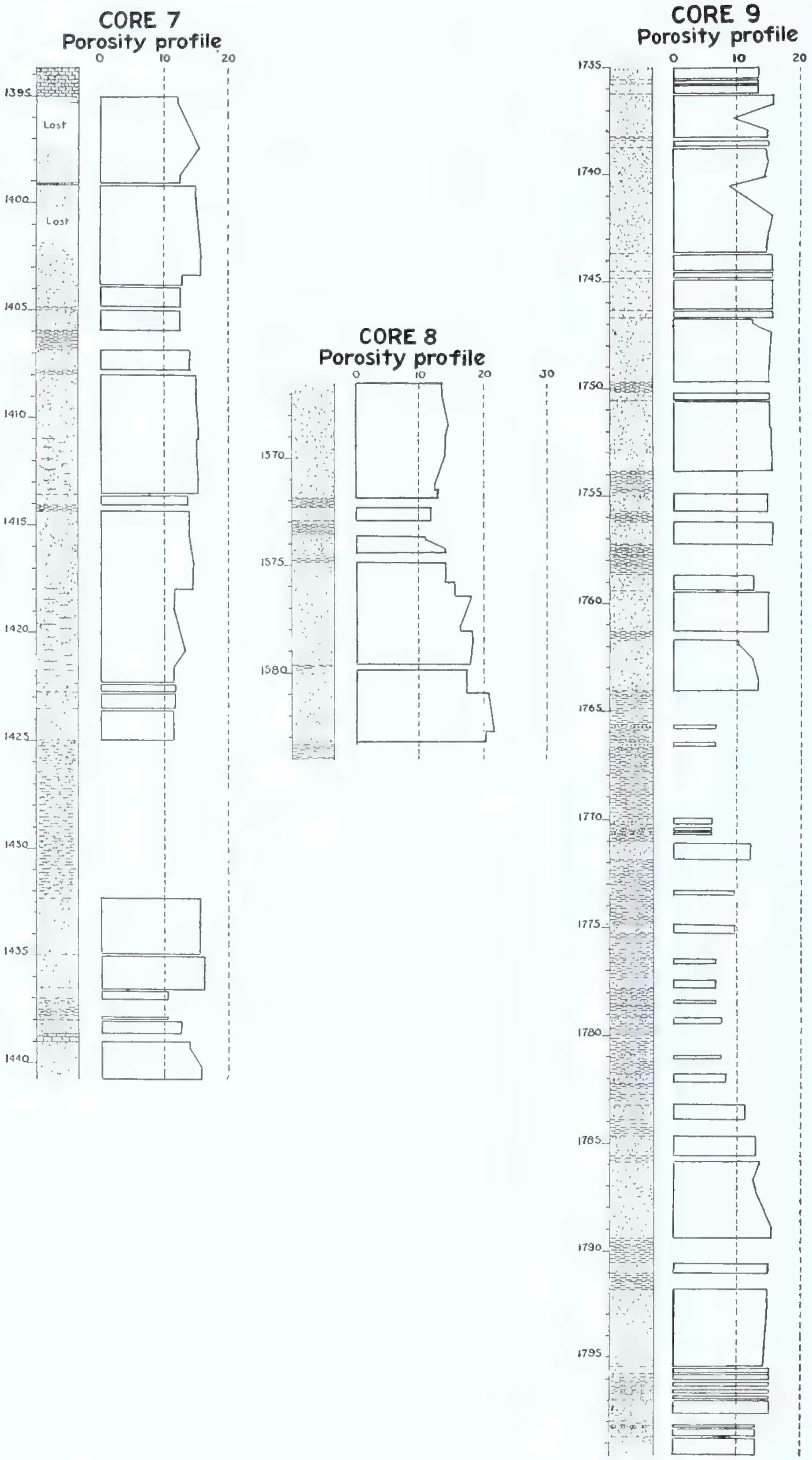


FIGURE 10. Sections and porosity profiles of cores 7, 8, and 9.

Core 2 Continued

Thickness feet	Description of strata	Depth to top feet
.58	Sandstone, moderately hard fine-grained chocolate-brown with some thin shale seams and lenses	1442.79
2.39	Sandstone, moderately hard fine-grained chocolate-brown	1443.37
.10	Shale	1445.76
3.58	Sandstone, moderately hard fine-grained chocolate-brown	1445.86
.85	Sandstone, moderately hard fine-grained chocolate-brown with numerous thin shale seams	1449.44
.50	Sandstone, moderately hard fine-grained chocolate-brown	1450.29
1.10	Sandstone, moderately hard fine-grained chocolate-brown with numerous thin shale seams	1450.79
1.84	Sandstone, moderately hard fine-grained chocolate-brown	1451.89
.15	Shale	1453.73
.40	Sandstone, hard fine-grained chocolate-brown with numerous thin shale seams	1453.88
.10	Shale	1454.28
.30	Sandstone, hard fine-grained chocolate-brown with numerous thin shale seams	1454.38
.30	Sandstone, hard fine-grained chocolate-brown	1454.68
1.24	Sandstone, hard fine-grained chocolate-brown with numerous thin shale seams	1454.98
1.70	Sandstone, moderately hard fine-grained chocolate-brown	1456.22
.05	Shale	1457.92
.35	Sandstone, moderately hard fine-grained chocolate-brown	1457.97
.10	Shale with thin seams of sandstone, fine-grained chocolate-brown	1458.32
.30	Sandstone, moderately hard fine-grained chocolate-brown	1458.42
.05	Shale	1458.72
.80	Sandstone, moderately hard fine-grained chocolate-brown	1458.77
.05	Shale	1459.57
2.00	Sandstone, moderately hard fine-grained chocolate-brown	1459.62
1.05	Shale with numerous seams of sandstone, fine-grained chocolate-brown	1461.62
1.17	Sandstone, moderately hard fine-grained chocolate-brown	1462.67
1.00	Shale with thin seams of sandstone, fine-grained chocolate-brown	1463.84
.75	Sandstone, hard fine-grained chocolate-brown	1464.84
.33	Shale with thin seams of sandstone, fine-grained chocolate-brown	1465.59
.50	Sandstone, hard fine-grained chocolate brown	1465.92
.75	Shale with thin seams of sandstone, fine-grained chocolate-brown	1466.42
.33	Sandstone, hard fine-grained chocolate-brown	1467.17
3.00	Shale	1467.50
.25	Sandstone, hard fine-grained chocolate-brown	1470.50
.75	Shale with some thin seams of sandstone, fine-grained chocolate-brown	1470.75
.50	Sandstone, hard fine-grained chocolate-brown	1471.50
.50	Shale	1472.00
.83	Sandstone, hard fine-grained chocolate-brown	1472.50
.92	Shale with some thin seams of sandstone, fine-grained chocolate-brown	1473.33
.25	Sandstone, hard fine-grained chocolate-brown	1474.25
.16	Shale	1474.50
.50	Sandstone, hard fine-grained chocolate-brown	1474.66
1.00	Shale	1475.16
1.00	Sandstone, hard fine-grained chocolate-brown	1476.16

Section of Core 3

	Top of Bradford Sand	1775.00
.55	Sandstone, hard fine-grained chocolate-brown	1775.00
.50	Shale	1775.55
1.10	Sandstone, moderately hard fine-grained chocolate-brown	1776.05
.10	Shale	1777.15
.60	Sandstone, moderately hard fine-grained chocolate-brown	1777.25
.10	Sandy shale	1777.85

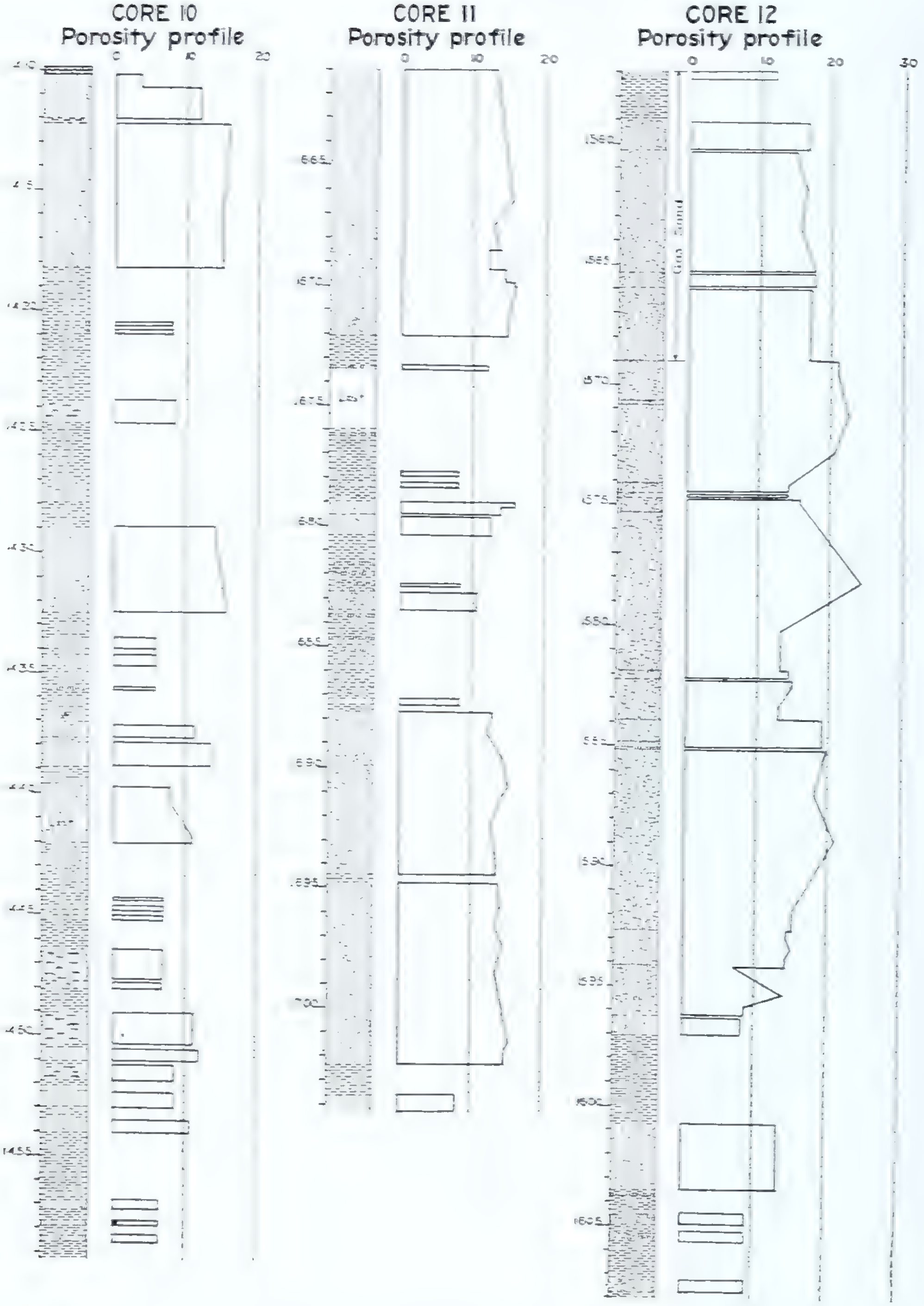


FIGURE 11. Sections and porosity profiles of cores 10, 11, and 12.

Core 3 Continued

Thickness feet	Description of strata	Depth to top feet
1.00	Sandstone, moderately hard fine-grained chocolate-brown	1777.95
.10	Shale	1778.95
.65	Sandstone, moderately hard fine-grained chocolate-brown	1779.05
.30	Shale	1779.70
1.30	Sandstone, moderately hard fine-grained chocolate-brown	1780.00
.40	Interbedded shale and hard fine-grained chocolate-brown sandstone	1781.30
.40	Sandstone, moderately hard fine-grained chocolate-brown	1781.70
.20	Shale	1782.10
.70	Sandstone, moderately hard fine-grained chocolate-brown with several thin shale seams near base	1782.30
	Top of oil pay	1783.00
2.15	Sandstone, moderately hard fine-grained chocolate-brown	1783.00
.60	Interbedded sandstone, hard fine-grained chocolate-brown and shale	1785.15
.75	Sandstone, moderately hard fine-grained chocolate-brown	1785.75
.20	Shale	1786.50
.50	Sandstone, hard fine-grained chocolate-brown with numerous shale seams	1786.70
.50	Sandstone, hard fine grained chocolate-brown	1787.20
.50	Shale	1787.70
1.70	Sandstone, moderately hard fine-grained chocolate-brown	1788.20
.60	Sandstone, hard fine-grained chocolate-brown with numerous shale seams	1789.90
.50	Sandstone, hard fine-grained chocolate-brown	1790.50
3.00	Sandstone, hard fine-grained chocolate-brown with numerous thin shale seams	1791.00
1.20	Sandstone, moderately hard fine-grained dark chocolate brown	1794.00
.20	Shale	1795.20
.40	Sandstone, moderately hard fine-grained dark chocolate brown	1795.40
.20	Shale	1795.80
.40	Sandstone, hard fine-grained dark chocolate-brown with numerous shale seams	1796.00
3.50	Sandstone, moderately hard fine-grained dark chocolate brown	1796.40
1.80	Sandstone, hard fine-grained dark chocolate-brown with numerous thin wavy shale seams	1799.90
.10	Shale	1801.70
.30	Sandstone, moderately hard fine-grained dark chocolate brown	1801.80
.10	Shale	1802.10
2.20	Sandstone, moderately hard fine-grained dark chocolate-brown	1802.20
.70	Shale with thin wavy seams of sandstone, hard fine-grained chocolate-brown	1804.40
3.90	Sandstone, moderately hard fine-grained dark chocolate-brown	1805.10
.80	Sandstone, hard fine-grained chocolate-brown with numerous thin wavy shale seams	1809.00
.30	Shale	1809.80
2.30	Sandstone, moderately hard fine-grained dark chocolate-brown	1810.10
2.30	Sandy gray shale with several thin seams of very hard sandstone, fine-grained chocolate brown	1812.40
.40	Sandstone, hard fine-grained chocolate-brown	1814.70
1.80	Sandy gray shale with several thin seams of sandstone, very hard fine-grained chocolate-brown	1815.10
1.20	Sandstone, moderately hard fine-grained dark chocolate-brown	1816.90
.20	Sandstone with shale seams, very hard fine-grained chocolate-brown	1818.10
.50	Sandstone, moderately hard fine grained dark chocolate-brown	1818.30
.10	Shale	1818.80
.60	Sandstone, very hard fine-grained dark chocolate-brown with numerous shale seams	1818.90
.60	Sandstone, moderately hard fine-grained dark chocolate-brown	1819.50

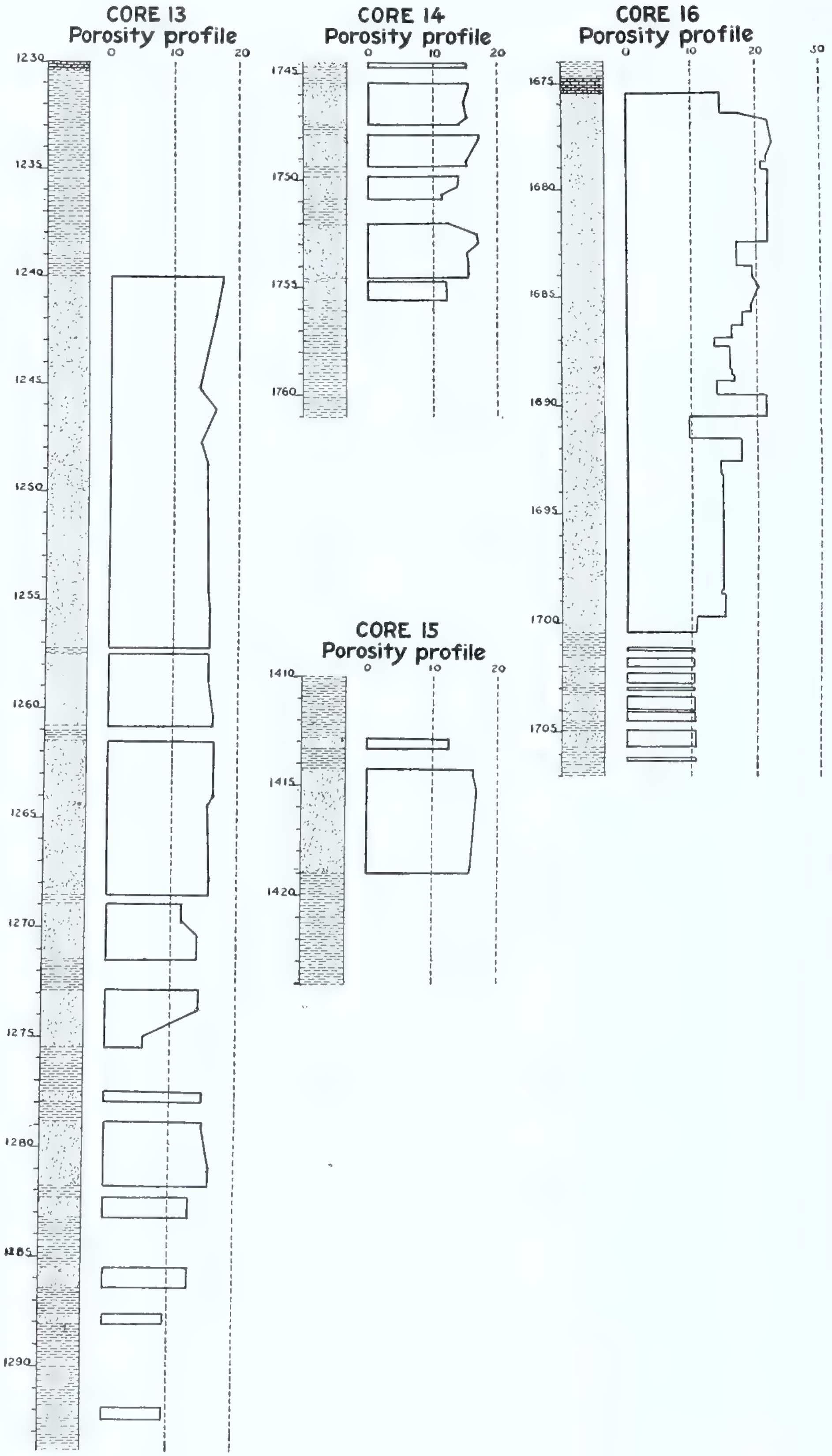


FIGURE 12. Sections and porosity profiles of cores 13, 14, 15, and 16.

Core 3 Continued

Thickness feet	Description of strata	Depth to top feet
1.40	Shale with numerous thin hard sandstone seams, fine-grained dark chocolate-brown	1820.10
1.40	Sandstone, moderately hard fine-grained dark chocolate-brown	1821.50
.20	Shale	1822.90
.70	Sandstone, moderately hard fine-grained dark chocolate-brown	1823.10
.05	Shale	1823.80
2.60	Sandstone, moderately hard fine-grained dark chocolate-brown	1823.85
.80	Shale	1826.45
.50	Sandstone, hard fine-grained dark chocolate-brown	1827.25
.15	Shale	1827.75
3.60	Sandstone, moderately hard fine-grained dark chocolate-brown	1827.90
3.20	Sandstone, hard fine-grained chocolate-brown with numerous seams of gray sandy shale	1831.50
4.00	Gray shale with numerous seams of very hard chocolate-brown sandstone	1834.70
1.50	Sandstone, moderately hard fine-grained dark chocolate-brown	1838.70
.80	Sandstone, very hard fine-grained chocolate-brown with numerous thin gray shale seams	1840.20
2.40	Shale with some thin seams of sandstone, very hard dark chocolate-brown	1841.00
.15	Shaly sandstone, hard fine-grained dark chocolate-brown	1843.40
2.95	Shale with some thin seams of sandstone, very hard fine-grained dark chocolate-brown	1843.55
.90	Sandstone, very hard fine-grained dark chocolate-brown, with numerous thin shale seams	1846.50
1.00	Shale, very hard fine-grained dark chocolate-brown with some thin sandstone seams	1847.40
.90	Sandstone, hard fine-grained dark chocolate-brown	1848.40
.90	Sandstone, hard fine grained dark chocolate-brown, with numerous shale seams	1849.30
.10	Shale	1850.20
.80	Sandstone, hard fine-grained chocolate-brown	1850.30
.40	Shale with some thin sandstone seams, very hard fine-grained dark chocolate-brown	1851.10

Section of Core 4

2.00	Shale	1553.00
1.50	Sandstone, hard gray calcareous (Caprock)	1555.00
	Top of Bradford sand	1556.50
3.71	Sandstone, moderately hard fine-grained chocolate-brown	1556.50
.04	Shale	1560.21
3.60	Sandstone, moderately hard fine-grained chocolate-brown	1560.25
.04	Shale	1563.85
.46	Sandstone, moderately hard fine-grained chocolate-brown, with several small shale lenses	1563.89
3.64	Sandstone, moderately hard fine-grained chocolate-brown	1564.35
.13	Shale with sandstone seam in middle, hard fine-grained chocolate-brown	1567.99
.45	Sandstone, moderately hard fine-grained chocolate-brown	1568.12
.08	Shale	1568.57
4.85	Sandstone, moderately hard fine-grained chocolate-brown	1568.65
.50	Shale with thin seams of sandstone, hard fine-grained chocolate-brown	1573.50
1.00	Sandstone, hard fine-grained chocolate-brown	1574.00
.50	Shale with thin seams of sandstone, hard fine-grained chocolate-brown	1575.00
.17	Sandstone, hard fine-grained chocolate-brown	1575.50
.50	Shale with thin seams of sandstone, hard fine-grained chocolate-brown	1575.67
.83	Sandstone, hard fine-grained dark chocolate-brown, with numerous thin shale seams	1576.17
.25	Shale with thin seams of sandstone, hard fine-grained chocolate-brown	1577.00
1.00	Sandstone, moderately hard fine-grained chocolate-brown	1577.25

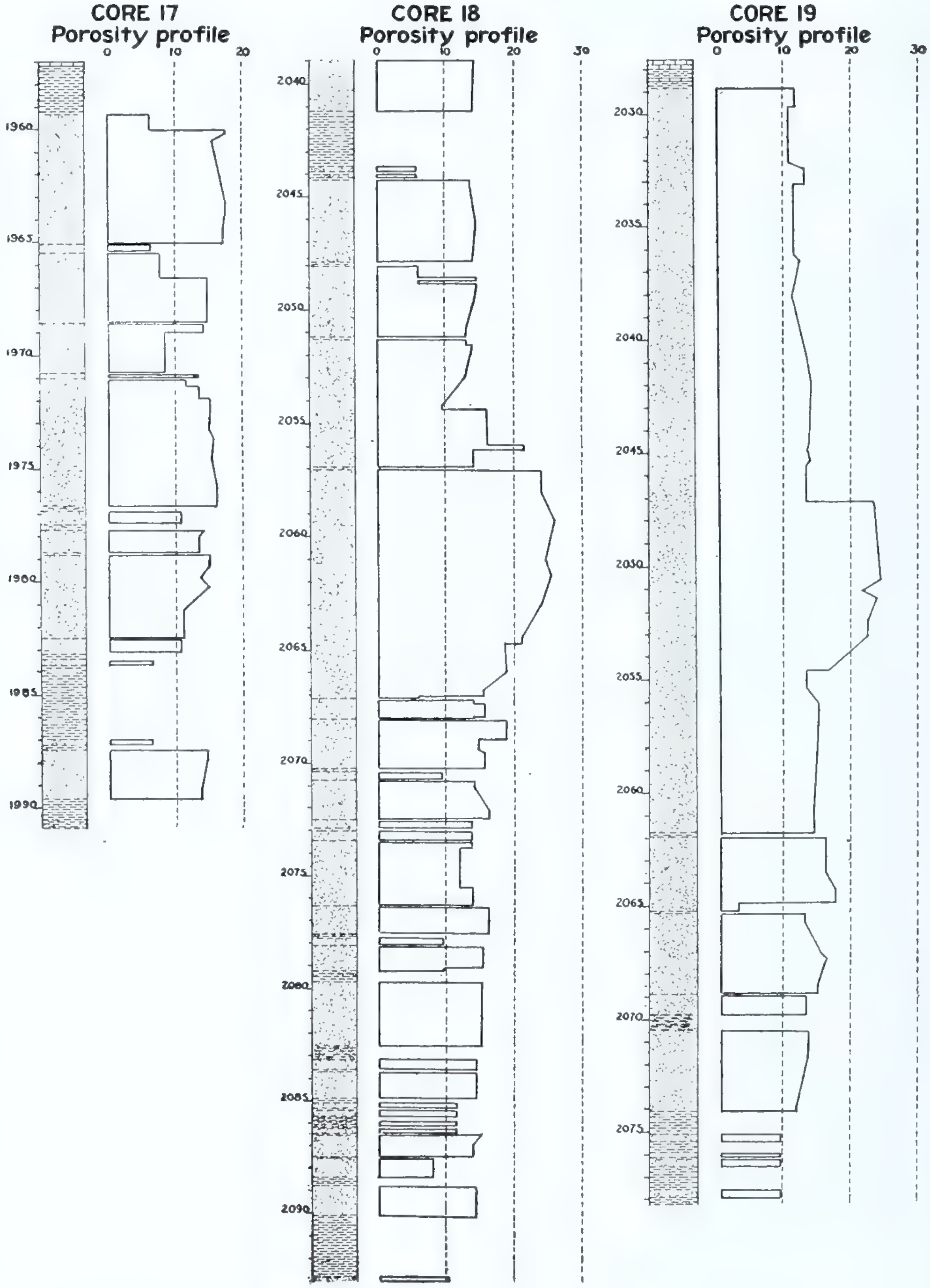


FIGURE 13. Sections and porosity profiles of cores 17, 18, and 19.

Core 4 Continued

Thickness feet	Description of strata	Depth to top feet
.25	Sandstone, hard fine-grained chocolate-brown with thin shale seams	1578.25
1.25	Sandstone, moderately hard fine-grained chocolate-brown	1578.50
.75	Sandstone, hard fine-grained chocolate-brown with numerous thin shale seams	1579.75
1.78	Sandstone, moderately hard fine-grained chocolate-brown	1580.50
.22	Shale	1582.28
.25	Sandstone, moderately hard fine-grained chocolate-brown	1582.50
.25	Shale	1582.75
.67	Shale with thin seams of hard sandstone, fine-grained chocolate-brown	1583.00
.25	Sandstone, moderately hard fine-grained chocolate-brown	1583.67
.08	Shale	1583.92
1.40	Sandstone, moderately hard fine-grained chocolate-brown	1584.00
.08	Shale	1585.40
.17	Sandstone, moderately hard fine-grained chocolate-brown	1585.48
.17	Shale	1585.65
.15	Sandstone, moderately hard fine-grained chocolate-brown	1585.82
.67	Shale with thin seams hard sandstone, fine-grained chocolate-brown	1585.97
.36	Sandstone, moderately hard fine-grained chocolate-brown	1586.64
.17	Shale with thin seams of sandstone, fine-grained chocolate-brown	1587.00
.50	Sandstone, moderately hard fine-grained chocolate-brown	1587.17
.33	Sandstone, moderately hard fine-grained chocolate-brown, with numerous thin seams of shale	1587.67
.67	Sandstone, moderately hard fine-grained chocolate-brown	1588.00
.17	Sandstone, moderately hard fine-grained chocolate-brown with thin shale seams	1588.67
2.80	Sandstone, moderately hard fine-grained chocolate-brown	1588.84
.08	Shale	1591.64
.20	Sandstone, moderately hard fine-grained chocolate-brown	1591.72
.17	Sandy shale	1591.92
.25	Sandstone, moderately hard fine-grained chocolate-brown	1592.09
.42	Sandstone, moderately hard fine-grained chocolate-brown with numerous thin shale seams	1592.34
.92	Sandstone, moderately hard fine-grained chocolate-brown	1592.76
.17	Sandstone, moderately hard fine-grained chocolate-brown with shale seams	1593.68
1.66	Sandstone, moderately hard fine-grained chocolate-brown	1593.85
.17	Sandstone, moderately hard fine-grained chocolate-brown with thin shale seams	1595.51
1.00	Sandstone, moderately hard fine-grained chocolate-brown	1595.68
.08	Sandstone, moderately hard fine-grained chocolate-brown with shale seams	1596.68
.50	Sandstone, moderately hard fine-grained chocolate-brown	1596.76
.08	Shale	1597.26
.17	Sandstone, moderately hard fine-grained chocolate-brown	1597.34
.33	Shale	1597.51
.25	Sandstone, moderately hard fine-grained chocolate-brown with numerous shale seams	1597.84
.25	Shale	1598.09
.08	Sandstone, moderately hard fine-grained chocolate-brown	1598.34

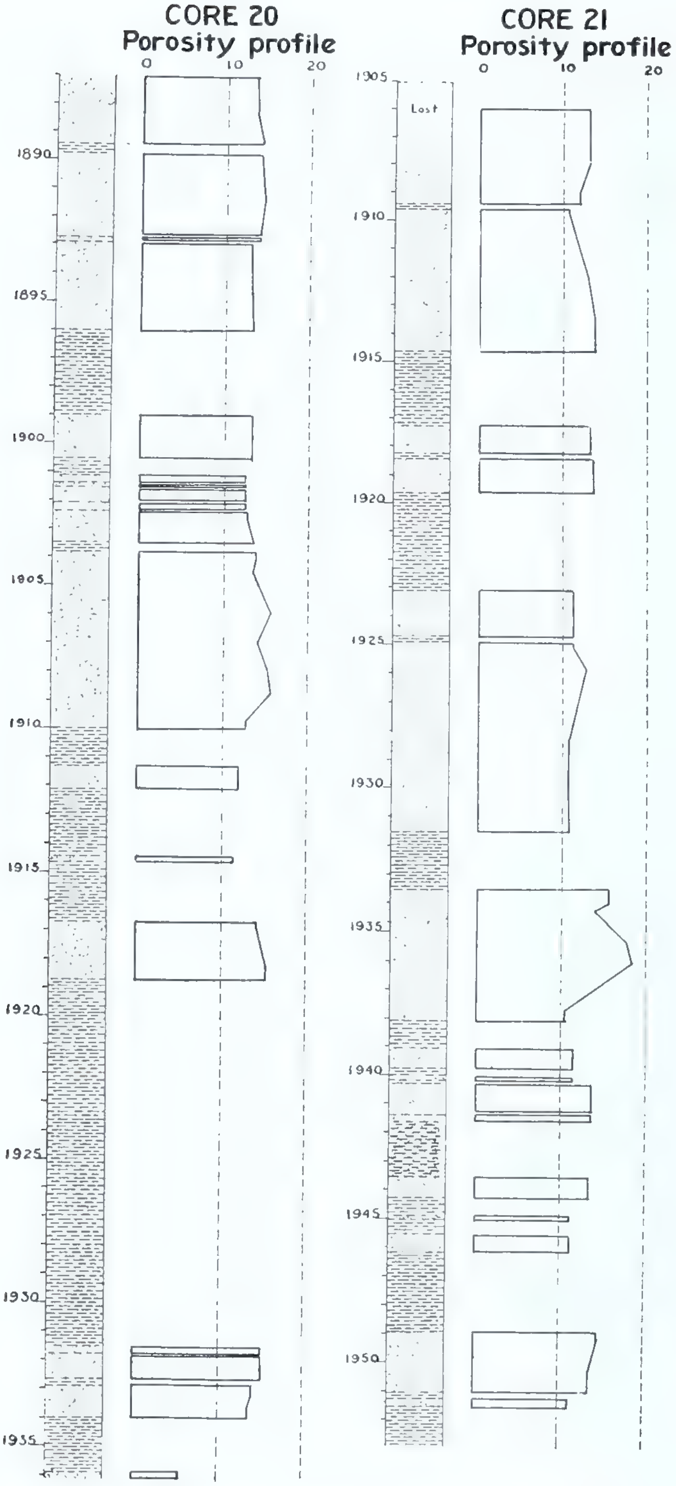


FIGURE 14. Sections and porosity profiles of cores 20 and 21.

Core 4 Continued

Thickness feet	Description of strata	Depth to top feet
.25	Sandstone, moderately hard fine-grained chocolate-brown with numerous shale seams	1598.42
.67	Sandstone, hard fine-grained chocolate-brown	1598.67
3.66	Sandstone, hard fine-grained chocolate-brown with numerous interbedded shale seams	1599.34
.50	Sandstone, moderately hard fine-grained chocolate-brown	1603.00
2.25	Sandstone, moderately hard fine-grained chocolate-brown with numerous shale seams	1603.50
3.91	Sandstone, moderately hard fine-grained chocolate-brown	1605.75
.25	Shale with thin seams of sandstone, fine-grained chocolate-brown	1609.66
2.17	Sandstone, moderately hard fine-grained chocolate-brown with numerous thin shale seams	1609.91
4.75	Shale with numerous thin fine-grained chocolate-brown sandstone seams	1612.08
.67	Shale	1616.83
1.00	Sandstone, moderately hard fine-grained chocolate-brown	1617.50
1.00	Shale	1618.50
1.00	Shale with numerous thin fine-grained chocolate-brown sandstone seams	1619.50
1.50	Shale	1620.50
.50	Shale with numerous thin fine-grained chocolate-brown sandstone seams	1622.00
.67	Sandstone, hard fine-grained chocolate-brown	1622.50

Section of Core 5

	Top of Bradford sand	1080.00
.58	Sandstone, hard very dark brownish-gray fine-grained with several thin shale lenses	1080.00
1.67	Sandstone, moderately hard dark chocolate-brown fine-grained	1080.58
.04	Shale	1082.25
.04	Sandy shale	1082.29
.02	Shale	1082.33
.90	Sandstone, moderately hard dark grayish-brown fine-grained	1082.35
1.75	Sandstone, hard very dark brownish-gray fine-grained (contains occasional thin shale lenses)	1083.25
.02	Shale	1085.00
.40	Sandstone, hard very dark brownish-gray fine-grained	1085.02
.02	Shale	1085.42
.02	Sandstone, Hard very dark brownish-gray fine-grained	1085.44
.04	Shale	1085.46
.02	Sandstone, hard very dark brownish-gray fine-grained	1085.50
.02	Shale	1085.52
2.63	Sandstone, moderately hard very dark chocolate-brown fine-grained (contains occasional thin shale lenses and wavy shale seams)	1085.54
1.83	Sandstone, hard very dark grayish-brown fine-grained (contains occasional thin shale lenses and wavy shale seams)	1088.17
3.75	Sandstone, hard very dark chocolate-brown fine-grained	1090.00
1.00	Sandstone, hard grayish-brown fine-grained	1093.75
2.08	Sandstone, hard dark grayish-brown fine-grained (contains occasional thin shale lenses and wavy shale seams)	1094.75
1.17	Sandstone, moderately hard very dark chocolate-brown fine-grained	1096.83
3.83	Sandstone, moderately hard dark chocolate-brown fine-grained	1098.00
.42	Shale	1101.83
.50	Sandstone, moderately hard dark chocolate-brown fine-grained with numerous shale lenses and thin shale seams	1102.25
.33	Shale with numerous thin seams of sandstone, hard dark chocolate-brown fine-grained	1102.75
17	Sandstone, hard very dark chocolate-brown fine-grained	1103.08

Core 5 Continued

Thickness feet	Description of strata	Depth to top feet
.50	Shale with numerous thin seams of hard very dark chocolate-brown fine-grained sandstone	1103.25
.75	Sandstone, hard very dark chocolate-brown fine-grained	1103.75
.92	Shale with numerous thin seams of hard very dark chocolate-brown fine-grained sandstone	1104.50
1.67	Sandstone, hard very dark chocolate-brown fine-grained with occasional thin shale lenses and thin shale seams	1105.42
1.58	Sandstone, hard very dark chocolate-brown fine-grained with numerous thin shale seams	1107.09
2.25	Shale with occasional thin seams of dark chocolate-brown sandstone	1108.67
1.33	Sandstone, hard light greenish-gray shaly	1110.92
1.83	Shale, dark greenish-gray sandy	1112.25
1.50	Sandstone, moderately hard light chocolate-brown fine-grained	1114.08
.33	Sandstone, moderately hard dark chocolate-brown fine-grained with numerous thin shale seams and lenses (cross-bedded)	1115.58
1.17	Sandstone, moderately hard light chocolate-brown fine-grained	1115.91
3.25	Shale, greenish-gray sandy	1117.08
67	Sandstone, dark, moderately hard, chocolate-brown, fine-grained, with numerous thin shale lenses and wavy shale seams (cross-bedded)	1120.33
.67	Sandstone, light, moderately hard, chocolate-brown, fine-grained	1121.00
.83	Sandstone, dark, moderately hard, chocolate-brown, fine-grained, with numerous thin shale seams and lenses (cross-bedded)	1121.67
2.75	Sandstone, dark, moderately hard, chocolate-brown, fine-grained	1122.50
.08	Shale, greenish-gray, sandy	1125.25
8.00	Sandstone, very dark, moderately hard, chocolate-brown, fine-grained (about half of this core was missing)	1125.33
.08	Shale, greenish-gray, sandy	1133.33
.67	Sandstone, very dark, moderately hard, chocolate-brown, fine-grained	1133.41
.04	Shale, greenish-gray, sandy	1134.08
1.04	Sandstone, moderately hard, very dark chocolate-brown, fine-grained	1134.12
.92	Shale, finely laminated and wavy greenish-gray, and sandstone, hard, dark chocolate-brown	1135.16
.84	Sandstone, moderately hard, very dark chocolate-brown, fine-grained	1136.08
1.67	Sandstone, hard, very dark chocolate-brown, fine-grained	1136.92
1.17	Sandstone, hard, dark chocolate-brown, fine-grained, with numerous thin wavy greenish-gray shale seams	1138.59
.16	Sandstone, hard, very dark chocolate-brown, fine-grained	1139.76
2.00	Sandstone, moderately hard, very dark chocolate-brown, fine-grained (about half of this core missing)	1139.92
.04	Shale	1141.92
.96	Sandstone, moderately hard, very dark chocolate-brown, fine-grained	1141.96
.75	Sandstone, hard, very dark chocolate-brown, fine-grained	1142.92
.33	Shale, with several thin seams of sandstone, hard, dark chocolate-brown	1143.67
1.83	Shale, greenish-gray	1144.00
.92	Sandstone, hard, very dark chocolate-brown, fine-grained, with several wavy thin shale seams	1145.83
.42	Shale, greenish-gray	1146.75
1.75	Sandstone, moderately hard, very dark chocolate-brown, fine-grained	1147.17
2.58	Shale, greenish-gray, with thin seams of sandstone, dark chocolate-brown	1148.92
.58	Sandstone, hard, dark chocolate-brown, with numerous thin shale seams	1151.50
.84	Sandstone, hard, dark chocolate-brown, fine-grained	1152.08

Section of Core 6

Thickness feet	Description of strata	Depth to top feet
.35	Limestone, fossiliferous	1724.00
1.96	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1724.35
.35	Shale	1726.31
	Top of Bradford sand	1726.66
1.05	Sandstone, hard, fine-grained, dark chocolate-brown	1726.66
.42	Sandstone, hard, fine-grained, dark chocolate-brown, with thin shale seams	1727.71
3.21	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1728.13
1.40	Shale, with thin seams sandstone near top, hard, fine-grained, dark chocolate-brown	1731.34
.42	Sandstone, hard, fine-grained, dark chocolate-brown	1732.74
.14	Shale	1733.16
5.40	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1733.30
.70	Shale	1738.70
.60	Sandstone, hard, fine-grained, chocolate-brown	1739.40
.60	Sandstone, hard, fine-grained, chocolate-brown, with numerous thin shale seams	1740.00
1.85	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1740.60
.33	Sandy shale	1742.45
1.75	Sandstone, moderately hard, fine-grained, dark chocolate-brown, with some thin shale seams	1742.78
.85	Shale, with some sandstone seams, hard, fine-grained, chocolate-brown	1744.53
2.37	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1745.38
.50	Shale, with some seams of sandstone, thin, hard, fine-grained, chocolate-brown	1747.75
2.75	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1748.25
.30	Interbedded shale, wavy and sandstone, hard, fine-grained, dark chocolate-brown	1751.00
2.00	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1751.30
.30	Sandstone, hard, fine-grained, dark chocolate-brown	1753.30
4.90	Shale	1753.60
.30	Sandstone, hard, fine-grained, chocolate-brown	1758.50
.70	Sandstone, very hard, fine-grained, chocolate-brown, with numerous shale seams	1758.80
.10	Shale	1759.50
2.80	Sandstone, moderately hard, fine-grained, chocolate-brown	1759.60
.05	Shale	1762.40
.25	Sandstone, very hard, fine-grained, chocolate-brown	1762.45
.40	Shale	1762.70
.10	Sandstone, very hard, fine-grained, chocolate-brown	1763.10
.25	Shale	1763.20
.85	Sandstone, hard, fine-grained, chocolate-brown	1763.45
.80	Shale, with some very hard sandstone seams, fine-grained, chocolate-brown	1764.30
1.00	Sandstone, moderately hard, fine-grained, chocolate-brown	1765.10
1.40	Shale, with some hard sandstone seams, fine-grained, chocolate-brown	1766.10

Section of Core 7

1.33	Sandstone, very hard, fine-grained, light-gray, calcareous	1393.67
	Top of Bradford sand	1395.00
.33	Sandstone, moderately hard, fine-grained, chocolate-brown	1395.00
2.08	Lost	1395.33
1.67	Sandstone, moderately hard, fine-grained, chocolate-brown	1397.41
.08	Sandstone, very hard, fine-grained, light-gray, calcareous	1399.08
1.00	Sandstone, moderately hard, fine-grained, chocolate-brown	1399.16
1.67	Lost	1400.16
1.50	Sandstone, moderately hard, fine-grained, chocolate-brown	1401.83

Core 7 Continued

Thickness feet	Description of strata	Depth to top feet
.48	Sandstone, platy micaceous, moderately hard, fine-grained, chocolate-brown	1403.33
.02	Shale	1403.81
1.00	Sandstone, platy micaceous, moderately hard, fine-grained, chocolate-brown	1403.83
.17	Shaly sandstone	1404.83
.92	Sandstone, platy micaceous, moderately hard, fine-grained, chocolate-brown	1405.00
.25	Shale	1405.92
.58	Shale, with thin seams and lenses of sandstone, hard, fine-grained, chocolate-brown	1406.17
.08	Shale	1406.75
.92	Sandstone, moderately hard, fine-grained, chocolate-brown	1406.83
.25	Shale	1407.75
3.00	Sandstone, moderately hard, fine-grained, chocolate-brown	1408.00
2.56	Sandstone, moderately hard, fine-grained, chocolate-brown, with a few thin shale seams and lenses	1411.00
.02	Shale	1413.56
.50	Sandstone, platy micaceous, hard, fine-grained, chocolate-brown	1413.58
25	Shale	1414.08
3.67	Sandstone, moderately hard, fine-grained, chocolate-brown	1414.33
4.33	Sandstone, hard, fine-grained, chocolate-brown, with occasional thin shale lenses	1418.00
.08	Shale	1422.33
.34	Sandstone, platy micaceous, hard, fine-grained, chocolate-brown	1422.41
.08	Shale	1422.75
.67	Sandstone, platy micaceous, hard, fine-grained chocolate-brown	1422.83
.08	Shale	1423.50
1.42	Sandstone, hard, fine-grained, chocolate-brown	1423.58
7.33	Shale, with some thin seams of sandstone, hard, fine-grained, chocolate-brown	1425.00
2.58	Sandstone, moderately hard, fine-grained chocolate-brown	1432.33
.09	Shale	1434.91
1.42	Sandstone, moderately hard, fine-grained chocolate-brown	1435.00
.08	Shale	1436.42
.50	Sandstone, hard, fine-grained chocolate-brown	1436.50
.33	Interbedded shale and sandstone, hard, fine-grained chocolate-brown	1437.00
.50	Shale	1437.33
.17	Sandstone, hard, fine-grained chocolate-brown	1437.83
.08	Shale	1438.00
.50	Sandstone, hard, fine-grained chocolate-brown	1438.08
.42	Sandstone, very hard fine-grained gray calcareous	1438.58
1.75	Sandstone, moderately hard, fine-grained chocolate-brown	1439.00
	Shale	

Section of Core 8

Thickness feet	Description of strata	Depth to top feet
	Top of Bradford sand	1566.50
2.15	Sandstone, moderately hard, fine-grained very dark chocolate-brown	1566.50
2.77	Sandstone, moderately hard, fine-grained, very dark chocolate brown	1568.65
.42	Sandstone, hard, fine-grained dark chocolate-brown	1571.42
.46	Shale	1571.84
.65	Sandstone, moderately hard, very fine-grained dark chocolate-brown	1572.30
.70	Sandy shale	1572.95
.80	Sandstone, hard, fine-grained, dark chocolate-brown	1573.65
.34	Shale	1574.45
.97	Sandstone, hard, fine-grained, dark chocolate-brown	1574.79
.67	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1575.76
1.65	Sandstone, friable, fine-grained, very dark chocolate-brown	1576.43
1.59	Sandstone, moderately hard, fine-grained, very dark chocolate-brown	1578.08
.21	Sandy shale	1579.67

Core 8 Continued

Thickness feet	Description of strata	Depth to top feet
1.02	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1579.88
1.80	Sandstone, moderately friable, fine grained, very dark chocolate-brown	1580.90
.50	Sandstone, friable, fine-grained, very dark chocolate-brown	1582.70
.17	Sandstone, hard, fine-grained, dark chocolate-brown	1583.20
.63	Shale	1583.37

Section of Core 9

.25	Sandstone, fine-grained, calcareous, very fossiliferous	
.75	Shale, fossiliferous	
.17	Sandstone, fine-grained, calcareous, very fossiliferous	
.42	Shale	
.17	Sandstone, fine-grained, calcareous, very fossiliferous	
.25	Shale	
	Top of Bradford Sand	1735.00
.58	Sandstone, fine-grained, moderately hard, chocolate-brown	1735.00
.05	Shale	1735.58
.20	Sandstone, fine-grained, moderately hard, chocolate-brown	1735.63
.05	Shale	1735.83
.45	Sandstone, fine-grained, moderately hard, chocolate-brown	1735.88
.05	Shale	1736.33
2.00	Sandstone, fine-grained, moderately hard, chocolate-brown	1736.38
.16	Shale	1738.38
.34	Sandstone, fine-grained, moderately hard, chocolate-brown	1738.54
.04	Shale	1738.88
4.75	Sandstone, fine-grained, moderately hard, chocolate-brown	1738.92
.04	Shale	1743.67
.79	Sandstone, fine-grained, moderately hard, chocolate-brown	1743.71
.08	Shale	1744.50
.21	Sandstone, fine-grained, moderately hard, chocolate-brown	1744.58
.09	Shale	1744.79
1.41	Sandstone, fine-grained, moderately hard, chocolate-brown	1744.88
.09	Shale	1746.29
.29	Sandstone, fine-grained, moderately hard, chocolate-brown	1746.38
.04	Shale	1746.67
2.92	Sandstone, fine-grained, moderately hard, chocolate-brown	1746.71
.52	Shale	1749.63
.31	Sandstone, fine-grained, moderately hard, chocolate-brown	1750.15
.04	Shale	1750.46
3.29	Sandstone, fine-grained, moderately hard, chocolate-brown	1750.50
1.04	Shale	1753.79
.84	Sandstone, fine-grained moderately hard, chocolate-brown	1754.83
.46	Shale	1755.67
.91	Sandstone, fine-grained, moderately hard, chocolate-brown	1756.13
.09	Sandy shale	1757.04
1.41	Shale	1757.13
.79	Sandstone, fine-grained, moderately hard, chocolate-brown, with carbonized plant stems in upper part	1758.54
.05	Shale	1759.33
1.91	Sandstone, fine-grained, moderately hard, chocolate-brown	1759.38
.43	Shale	1761.29
2.33	Sandstone, fine-grained, moderately hard, chocolate-brown	1761.71
1.59	Shale	1764.04
.04	Sandstone, fine-grained, hard	1765.63
.79	Shale	1765.67
.08	Sandstone, fine-grained, hard	1766.46
3.38	Shale	1766.54

Core 9 Continued

Thickness feet	Description of strata	Depth to top feet
.25	Sandstone, fine-grained, very hard, chocolate-brown	1769.92
.16	Shale	1770.17
.05	Sandstone, fine-grained, very hard, chocolate-brown	1770.33
.08	Shale	1770.38
.08	Sandstone, fine-grained, very hard, chocolate-brown	1770.46
.42	Shale	1770.54
.71	Sandstone, fine-grained, very hard, chocolate-brown	1770.96
.41	Sandy shale	1771.67
1.00	Shale	1772.08
.17	Sandstone, fine-grained, very hard, chocolate-brown	1773.08
1.42	Shale	1773.25
.41	Sandstone, fine-grained, very hard, chocolate-brown	1774.67
1.21	Shale	1775.08
.04	Sandstone, fine-grained, very hard, chocolate-brown	1776.29
.92	Shale	1776.33
.42	Sandstone, fine-grained, very hard, chocolate-brown	1777.25
.54	Shale	1777.67
.04	Sandstone, fine-grained, very hard, chocolate-brown	1778.21
.75	Shale	1778.25
.25	Sandstone, fine-grained, very hard, chocolate-brown	1779.00
1.54	Shale	1779.25
.04	Sandstone, fine-grained, very hard, chocolate-brown	1780.79
.09	Shale	1780.83
.16	Sandy shale	1780.92
.75	Shale	1781.08
.42	Sandstone, fine-grained, very hard, chocolate-brown	1781.83
1.00	Shale	1782.25
.67	Sandstone, fine-grained, very hard, chocolate-brown	1783.25
.75	Shale	1783.92
.91	Sandstone, fine-grained, hard, chocolate-brown	1784.67
.25	Shale	1785.58
3.67	Sandstone, fine-grained, hard, chocolate-brown	1785.83
.67	Shale	1789.50
.08	Sandy shale	1790.17
.42	Shale	1790.25
.41	Sandstone, fine-grained, very hard, chocolate-brown	1790.67
.84	Shale	1791.08
3.58	Sandstone, fine-grained, hard, chocolate-brown	1791.92
.04	Shale	1795.50
.21	Sandstone, fine-grained, hard, chocolate-brown	1795.54
.08	Shale	1795.75
.09	Sandstone, fine-grained, hard, chocolate-brown	1795.83
.08	Shale	1795.92
.08	Sandstone, fine-grained, hard, chocolate-brown	1796.00
.13	Shale	1796.08
.04	Sandstone, fine-grained, hard, chocolate-brown	1796.21
.29	Shale	1796.25
.09	Sandstone, fine-grained, hard, chocolate-brown	1796.54
.12	Shale	1796.63
.13	Sandy shale	1796.75
.12	Sandstone, fine-grained, hard, chocolate-brown	1796.88
.08	Shale	1797.00
.59	Sandstone, fine-grained, hard, chocolate-brown	1797.08
.58	Sandy shale	1797.67
.13	Sandstone, fine-grained, hard, chocolate-brown	1798.25
.08	Sandy shale	1798.38
.29	Sandstone, fine-grained, hard, chocolate-brown	1798.46
.08	Shale	1798.75
.75	Sandstone, fine-grained, hard, chocolate-brown	1798.83
	Shale	

Section of Core 10

.33	Sandstone, calcareous (cap rock)	1409.92
	Top of Bradford sand	1410.25
.50	Sandstone, very hard, fine-grained, brownish-gray	1410.25
1.33	Sandstone, hard, fine-grained, chocolate-brown	1410.75
.17	Sandstone, hard, fine-grained, chocolate-brown, with numerous shale lenses	1412.08
6.00	Sandstone, moderately hard, fine-grained, chocolate-brown	1412.25
2.25	Shale with several thin seams of hard, fine-grained chocolate-brown sandstone	1418.25
.17	Sandstone, hard, fine-grained, chocolate-brown	1420.50
.16	Shale	1420.67
.17	Sandstone, hard, fine-grained, chocolate-brown	1420.83

Core 10 Continued

Thickness feet	Description of strata	Depth to top feet
2.75	Shale with several thin seams of sandstone, hard, fine-grained, chocolate-brown	1421.00
.42	Sandstone, hard, fine-grained, chocolate-brown, with numerous small shale lenses	1423.75
.50	Sandstone, hard, fine-grained, chocolate-brown	1424.17
4.25	Shale with several thin seams of sandstone, hard, fine-grained, chocolate-brown	1424.67
3.67	Sandstone, moderately hard, fine-grained, chocolate-brown	1428.92
1.00	Shale with thin seams of sandstone, hard, fine-grained, chocolate-brown	1432.59
.41	Sandstone, hard, fine-grained, chocolate-brown	1433.59
.25	Shale	1434.00
.50	Sandstone, hard, fine-grained, chocolate-brown	1434.25
.83	Shale	1434.75
.17	Sandstone, hard, fine-grained, chocolate-brown	1435.58
1.42	Shale	1435.75
.50	Sandstone, moderately hard, fine-grained, chocolate-brown	1437.17
.17	Shale	1437.67
1.00	Sandstone, moderately hard, fine-grained, chocolate-brown	1437.84
.83	Shale with a few thin seams of sandstone, hard, fine-grained, chocolate-brown	1438.84
1.25	Sandstone, hard, fine-grained, chocolate-brown	1439.67
.58	Lost	1440.92
.50	Sandstone, hard, fine-grained, chocolate-brown	1441.50
2.25	Shale	1442.00
.17	Sandstone, hard, fine-grained, chocolate-brown	1444.25
.15	Shale	1442.42
.25	Sandstone, hard, fine-grained, chocolate-brown	1444.57
.25	Shale	1444.82
.18	Sandstone, hard, fine-grained, chocolate-brown	1445.07
1.17	Shale	1445.25
1.33	Sandstone, hard, fine-grained, chocolate-brown, with numerous thin shale seams and lenses	1446.42
.08	Shale	1447.75
.33	Sandstone, hard, fine-grained, chocolate-brown, with numerous thin shale seams and lenses	1447.83
.92	Shale, fossiliferous	1448.16
1.33	Sandstone, hard, fine-grained, chocolate-brown, with a few thin shale seams and lenses	1449.08
.17	Shale	1450.41
.50	Sandstone, hard, fine-grained, chocolate-brown	1450.58
.17	Shale	1451.08
.58	Sandstone, hard, fine-grained, chocolate-brown, with several shale lenses	1451.25
.50	Shale	1451.83
.67	Sandstone, very hard, cross-bedded, platy, fine-grained, chocolate-brown	1452.33
.50	Shale	1453.00
.58	Sandstone, very hard, cross-bedded, platy, fine-grained, chocolate-brown	1453.50
2.75	Shale	1454.08
.42	Sandstone, very hard, cross-bedded, platy, fine-grained, chocolate-brown	1456.83
.42	Shale	1457.25
.25	Sandstone, very hard, fine-grained, chocolate-brown	1457.67
.42	Shale	1457.92
.25	Sandstone, very hard, fine-grained, chocolate-brown	1458.34
.66	Shale	1458.59

Section of Core 11

	Top of Bradford sand	1661.00
7.50	Sandstone, moderately hard, fine-grained, chocolate-brown	1661.00
.83	Sandstone, friable, moderately fine-grained, chocolate-brown	1668.50
.50	Sandstone, moderately hard, fine-grained, chocolate-brown	1669.33
.17	Sandstone, friable, moderately fine-grained, chocolate-brown	1669.83
2.08	Sandstone, moderately hard, fine-grained, chocolate-brown	1670.00

Core 11 Continued

Thickness feet	Description of strata	Depth to top feet
1.25	Shale	1672.08
.17	Sandstone, very hard, fine-grained, chocolate-brown	1673.33
2.50	Lost	1673.50
.13	Shale	1676.00
.04	Sandstone, moderately hard, fine-grained, chocolate-brown	1676.13
1.50	Shale	1676.17
.17	Sandstone, moderately hard, fine-grained, chocolate-brown	1677.67
.33	Shale	1677.84
.21	Sandstone, moderately hard, fine-grained, chocolate-brown	1678.17
.33	Shale	1678.38
.08	Sandstone, moderately hard, fine-grained, chocolate-brown	1678.71
.13	Shale	1678.79
.25	Sandstone, moderately hard, fine-grained, chocolate-brown	1678.92
.38	Sandstone, hard, fine-grained, chocolate-brown	1679.17
.08	Shale	1679.55
.79	Sandstone, hard, fine-grained, chocolate-brown	1679.63
1.17	Shale	1680.42
.02	Sandstone, hard, fine-grained, chocolate-brown	1681.59
.17	Shale	1681.61
.06	Sandstone, hard, fine-grained, chocolate-brown	1681.78
.02	Shale	1681.84
.17	Sandstone, hard, fine-grained, chocolate-brown	1681.86
.33	Shale	1682.03
.06	Sandstone, hard, fine-grained, chocolate-brown	1682.36
.10	Shale	1682.42
.06	Sandy shale	1682.52
.06	Sandstone, hard, fine-grained, chocolate-brown	1682.58
.08	Shale	1682.64
.79	Sandstone, hard, fine-grained, chocolate-brown	1682.72
.13	Shale	1683.51
.08	Sandstone, hard, fine-grained, chocolate-brown	1683.64
.81	Shale	1683.72
.06	Sandstone, hard, fine-grained, chocolate-brown	1684.53
.46	Sandy shale	1684.59
.04	Sandstone, hard, fine-grained, chocolate-brown	1685.05
.50	Shale	1685.09
.04	Sandstone, hard, fine-grained, chocolate-brown	1685.59
.06	Sandy shale	1685.63
.23	Sandstone, moderately hard, fine-grained, chocolate-brown	1685.69
.44	Shale	1685.92
.04	Sandstone, hard, fine-grained, chocolate-brown	1686.36
.10	Shale	1686.40
.06	Sandstone, hard, fine-grained, chocolate-brown	1686.50
.10	Shale	1686.56
.04	Sandstone, hard, fine-grained, chocolate-brown	1686.66
.21	Shale	1686.70
.21	Sandstone, hard, fine-grained, chocolate-brown	1686.91
.29	Shale	1687.12
6.88	Sandstone, moderately hard, fine-grained, chocolate-brown	1687.41
.38	Shale	1694.29
7.63	Sandstone, moderately hard, fine-grained, chocolate-brown	1694.67
1.38	Shale	1702.30
.58	Sandstone, hard, fine-grained, chocolate-brown	1703.68
	Shale	

Section of Core 12

Thickness feet	Description of strata	Depth to top feet
	Top of Bradford sand	1557.00
.33	Sandstone, hard, fine-grained, dark grayish-brown	1557.00
1.75	Shale, greenish-gray	1557.33
1.13	Sandstone, moderately hard, fine-grained, grayish-brown	1559.08
.02	Sandy shale	1560.21
5.08	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1560.23
.02	Sandy shale	1565.31
.65	Sandstone, moderately hard, fine-grained, grayish-brown	1565.33

Core 12 Continued

Thickness feet	Description of strata	Depth to top feet
.02	Shale	1565.98
3.00	Sandstone, moderately friable, fine-grained, grayish-brown	1566.00
	Probable bottom of gas pay	
1.67	Sandstone, friable, fine-grained, chocolate-brown	1569.00
.13	Sandstone, hard, fine-grained, chocolate-brown	1570.67
3.20	Sandstone, friable, fine-grained, chocolate-brown	1570.80
.42	Sandstone, moderately hard, fine-grained dark grayish-brown	1574.00
.02	Shale	1574.42
.21	Sandstone, moderately hard, fine-grained, dark grayish-brown	1574.44
.04	Shale	1574.65
.58	Sandstone, moderately hard, fine-grained, dark grayish-brown	1574.69
6.58	Sandstone, moderately friable, fine-grained, chocolate-brown	1575.27
.38	Sandstone, moderately hard, fine-grained, grayish-brown	1581.85
.04	Sandy shale	1582.23
1.67	Sandstone, hard, fine-grained, grayish-brown	1582.27
.98	Sandstone, moderately friable, fine-grained, chocolate-brown	1583.94
.17	Sandstone, hard, fine-grained, grayish-brown	1584.92
.02	Sandstone, hard, fine-grained, light greenish-gray calcareous	1585.09
7.58	Sandstone, moderately friable, fine-grained, chocolate-brown	1585.11
1.46	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1592.69
2.15	Sandstone, hard, fine-grained, grayish-brown	1594.15
.06	Shale	1596.30
.75	Sandstone, hard, fine-grained, dark grayish-brown	1596.36
.67	Shale	1597.11
2.42	Sandy shale	1597.78
.50	Shale	1600.20
2.80	Sandstone, hard, fine-grained, dark brownish-gray	1600.70
.15	Shale	1603.50
.10	Sandstone, hard, fine-grained, grayish-brown	1603.65
.63	Sandy shale	1603.75
.06	Shale	1604.38
.50	Sandstone, hard, fine-grained, dark grayish-brown	1604.44
.25	Shale	1604.94
.40	Sandstone, hard, fine-grained, dark grayish-brown	1605.19
1.67	Shale	1605.59
.50	Sandstone, hard, fine-grained, greenish-gray	1607.26
.24	Sandy shale	1607.76

Section of Core 13

.40	Shale, gray, calcareous, highly fossiliferous	1230.00
5.15	Shale, sparsely fossiliferous	1230.40
2.85	Shale, calcareous, highly fossiliferous	1235.55
.60	Sandstone, fine-grained, gray	1238.40
.40	Shale, gray, calcareous, fossiliferous	1239.00
.05	Dark shale	1239.40
.55	Shale, gray, calcareous, fossiliferous	1239.45
	Top of Bradford Sand	1240.00
17.25	Sandstone, fine-grained, brown	1240.00
.25	Shale, gray, calcareous	1257.25
3.30	Sandstone, fine-grained, chocolate-brown	1257.50
.70	Shale	1260.80
7.10	Sandstone, fine-grained brown	1261.50
.39	Shale	1268.60
2.53	Sandstone, fine-grained, brown	1268.99
1.35	Shale	1271.52
2.66	Sandstone, fine-grained, brown	1272.87
2.00	Shale	1275.53
.45	Sandstone, fine-grained, brown	1277.53
.85	Shale	1277.98
2.95	Sandstone, fine-grained, brown	1278.83
.50	Shale	1281.78
.90	Sandstone, fine-grained, brown	1282.28
2.23	Shale	1283.18

Core 13 Continued

Thickness feet	Description of strata	Depth to top feet
1.00	Sandstone, fine-grained, dark-brown	1285.41
1.18	Shale	1286.41
.45	Sandstone, fine-grained, dark-brown	1287.59
3.75	Shale	1288.04
.54	Sandstone, fine-grained, dark brown	1291.79
1.50	Shale	1292.33

Section of Core 14

	Top of Bradford sand	1744.50
.17	Sandstone, moderately hard, fine-grained, chocolate-brown	1744.50
.75	Shale with thin seams of hard fine-grained chocolate-brown sandstone	1744.67
1.92	Sandstone, moderately hard, fine-grained, chocolate-brown	1745.42
.50	Shale	1747.34
1.50	Sandstone, moderately hard, fine-grained, chocolate-brown	1747.84
.42	Shale	1749.34
1.08	Sandstone, hard, fine-grained, chocolate-brown	1749.76
1.17	Shale with thin seams of hard, fine-grained, chocolate-brown sandstone	1750.84
2.50	Sandstone, moderately hard, fine-grained, chocolate-brown	1752.01
.17	Shale	1754.51
.83	Sandstone, hard, fine-grained, chocolate-brown	1754.68
2.00	Shale with thin seams of hard fine-grained chocolate-brown sandstone	1755.51
3.49	Shale	1757.51

Section of Core 15

2.80	Shale with some thin seams of very hard fine-grained brownish-gray sandstone	1410.00
	Top of Bradford sand	1412.80
.50	Sandstone, very hard, fine-grained, grayish-brown	1412.80
.90	Shale with several thin seams of very hard fine-grained sandstone, brownish-gray	1413.30
4.80	Sandstone, moderately hard, fine-grained, chocolate-brown	1414.20
5.00	Shale	1419.00

Section of Core 16

.67	Shale	1674.00
.81	Sandstone, hard, fine-grained, gray, calcareous	1674.67
	Top of Bradford sand	1675.48
1.00	Sandstone, moderately hard, fine-grained, brown	1675.48
2.21	Sandstone, moderately friable, fine-grained, brown	1676.48
.46	Sandstone, moderately hard, fine-grained, brown	1678.69
3.23	Sandstone, friable, fine-grained, brown	1679.15
1.12	Sandstone, moderately hard, fine-grained, brown	1682.38
2.21	Sandstone, moderately friable, fine-grained, dark-brown	1683.50
.62	Sandstone, moderately hard, fine-grained, dark-brown	1685.71
.63	Sandstone, moderately friable, fine-grained, dark-brown	1686.33
.37	Sandstone, moderately hard, fine-grained, dark-brown	1686.96
.98	Sandstone, moderately friable, fine-grained, dark-brown	1687.33
.27	Sandstone, moderately hard, fine-grained, dark-brown	1688.31
.30	Sandstone, moderately friable, fine-grained, dark-brown	1688.58
.62	Sandstone, moderately hard, fine-grained, dark-brown	1688.88
1.00	Sandstone, moderately friable, fine-grained, dark-brown	1689.50
1.00	Sandstone, hard, fine-grained, brown	1690.50
1.06	Sandstone, moderately friable, fine-grained, brown	1691.50

Core 16 Continued

Thickness feet	Description of strata	Depth to top feet
.63	Sandstone, hard, fine-grained, brown	1692.56
2.00	Sandstone, moderately friable, fine-grained, brown	1693.19
1.31	Sandstone, hard, fine-grained, brown	1695.19
1.96	Sandstone, moderately friable, fine-grained, dark-brown	1696.50
.12	Sandstone, hard, fine-grained, dark-brown	1698.46
1.09	Sandstone, moderately friable, fine-grained, dark-brown	1698.58
.73	Sandstone, hard, fine-grained, dark-brown	1699.67
.66	Shale	1700.40
.11	Sandstone, hard, fine-grained, dark-brown	1701.06
.33	Shale	1701.17
.46	Sandstone, very hard, fine-grained, dark brownish-gray	1701.50
.33	Shale	1701.96
.42	Sandstone, very hard, fine-grained, dark brownish-gray	1702.29
.17	Shale	1702.71
.16	Sandstone, very hard, fine-grained, dark brownish-gray	1702.88
.25	Shale	1703.04
.75	Sandstone, very hard, fine-grained, dark brownish-gray	1703.29
.09	Shale	1704.04
.41	Sandstone, very hard, fine-grained, dark brownish-gray	1704.13
.42	Shale	1704.54
.75	Sandstone, very hard, fine-grained, dark brownish-gray	1704.96
.50	Shale	1705.71
.12	Sandstone, extremely hard, fine-grained, dark brownish-gray	1706.21
.67	Shale	1706.33

Section of Core 17

.20	Limestone, fossiliferous	1957.00
2.10	Shale with several thin fossiliferous limestone seams	1957.20
	Top of Bradford sand	1959.30
.70	Sandstone, hard, fine-grained, brownish-gray	1959.30
3.40	Sandstone, moderately hard, fine-grained, chocolate-brown	1960.00
1.65	Sandstone, friable, fine-grained, chocolate-brown	1963.40
.05	Shale	1965.05
.35	Sandstone, very hard, fine-grained, grayish-brown, platy	1965.10
.05	Shale	1965.45
1.10	Sandstone, hard, fine-grained, grayish-brown, platy	1965.50
2.00	Sandstone, moderately friable, fine-grained, chocolate-brown	1966.60
.05	Shale	1968.60
.35	Sandstone, moderately friable, fine-grained, chocolate-brown	1968.65
1.75	Sandstone, hard, very fine-grained, chocolate-brown	1969.00
.05	Shale	1970.75
.20	Sandstone, moderately hard, fine-grained, chocolate-brown	1970.80
.05	Shale	1971.00
.35	Sandstone, hard, very fine-grained, chocolate-brown	1971.05
.50	Sandstone, moderately hard, fine-grained, chocolate-brown	1971.40
4.75	Sandstone, moderately friable, fine-grained, chocolate-brown	1971.90
.25	Sandstone, very hard, fine-grained, chocolate-brown, with several thin shale seams	1976.65
.55	Sandstone, hard, fine-grained, chocolate-brown	1976.90
.05	Shale	1977.45
.25	Sandstone, hard, fine-grained, chocolate-brown, with several thin shale seams	1977.50
1.00	Sandstone, moderately hard, fine-grained, chocolate-brown	1977.75
.10	Sandstone, very hard, fine-grained, chocolate-brown, with shale seams	1978.75

Core 17 Continued

Thickness feet	Description of strata	Depth to top feet
3.67	Sandstone, moderately hard, fine-grained, chocolate-brown	1978.85
.05	Shale	1982.52
.65	Sandstone, hard, fine-grained, chocolate-brown	1982.57
.25	Shale	1983.22
.20	Sandstone, very hard, fine-grained, chocolate-brown	1983.47
3.30	Shale with a few thin seams of sandstone, very hard, fine-grained, chocolate-brown	1983.67
.25	Sandstone, very hard, fine-grained, chocolate-brown	1986.97
.20	Shale	1987.22
2.20	Sandstone, moderately hard, fine-grained, chocolate-brown	1987.42
1.30	Shale with a few thin seams of hard sandstone, fine-grained, chocolate-brown	1989.62

Section of Core 18

	Top of Bradford Sand	2039.00
2.00	Sandstone, moderately hard, fine-grained, chocolate-brown	2039.00
.22	Sandstone, hard, fine-grained, light chocolate-brown	2041.00
2.47	Shale	2041.22
.22	Sandstone, hard, fine-grained, light chocolate-brown	2043.69
.16	Shale	2043.91
.16	Sandstone, hard, fine-grained, light chocolate-brown	2044.07
.10	Shale	2044.23
3.64	Sandstone, moderately hard, fine-grained, chocolate-brown	2044.33
.21	Interbedded shale and sandstone, hard, fine-grained, chocolate-brown	2047.97
.14	Sandstone, hard, fine-grained, chocolate-brown	2048.18
.35	Sandstone, very hard, fine-grained, light-gray	2048.32
10	Sandstone, moderately hard, fine-grained, chocolate-brown	2048.67
.11	Sandstone, very hard, fine-grained, light-gray	2048.77
2.33	Sandstone, moderately hard, fine-grained, chocolate-brown	2048.88
.14	Interbedded shale and sandstone, hard, fine-grained, chocolate-brown	2051.21
.20	Sandstone, moderately hard, fine-grained, chocolate-brown	2051.35
2.88	Sandstone moderately friable, fine-grained, chocolate-brown	2051.55
1.55	Sandstone, moderately hard, fine-grained, chocolate-brown	2054.43
.20	Sandstone, friable, fine-grained, chocolate-brown	2055.98
.74	Sandstone, moderately hard, fine-grained, chocolate-brown	2056.18
.11	Interbedded shale and sandstone, hard, fine-grained, chocolate-brown	2056.92
7.67	Sandstone, friable, fine-grained, dark chocolate-brown	2057.03
2.30	Sandstone, moderately hard, fine-grained, chocolate-brown	2064.70
.05	Sandstone, hard, fine-grained, chocolate-brown	2067.00
.05	Shale	2067.05
.15	Sandstone, moderately hard, fine-grained, chocolate-brown	2067.10
.60	Sandstone, friable, fine-grained, chocolate-brown	2067.25
.15	Sandstone, moderately hard, fine-grained, chocolate-brown	2067.85
.05	Shale	2068.00
.85	Sandstone, friable, fine-grained, chocolate-brown	2068.05
1.30	Sandstone, moderately hard, fine-grained, chocolate-brown	2068.90
.05	Shale	2070.20
.10	Sandstone, hard, fine-grained, chocolate-brown	2070.25
.05	Shale	2070.35
.35	Sandstone, hard, fine-grained, grayish-brown	2070.40
.05	Shale	2070.75
1.76	Sandstone, moderately hard, fine-grained, chocolate-brown	2070.80
.02	Shale	2072.56
.37	Sandstone, moderately hard, fine-grained, chocolate-brown	2072.58
.10	Interbedded shale and sandstone, very hard, fine-grained, chocolate-brown	2072.95

Core 18 Continued

Thickness feet	Description of strata	Depth to top feet
.35	Sandstone, moderately hard, fine-grained, chocolate-brown	2073.05
.05	Shale	2073.40
.30	Sandstone, moderately hard, fine-grained, chocolate-brown	2073.45
1.71	Sandstone, hard, fine-grained, dark grayish-brown, with thin wavy shale lenses	2073.75
.85	Sandstone, moderately hard, fine-grained, chocolate-brown	2075.46
.07	Shale	2076.31
1.24	Sandstone, moderately hard, fine-grained, chocolate-brown	2076.38
.07	Shale	2077.62
.07	Sandstone, hard, fine-grained, chocolate-brown	2077.69
.13	Shale with thin lenses of sandstone, hard, fine-grained, chocolate-brown	2077.76
.20	Sandstone, hard, fine-grained, chocolate-brown	2077.89
.07	Shale	2078.09
1.01	Sandstone, moderately hard, fine-grained, chocolate-brown	2078.16
.20	Sandstone, hard, fine-grained, chocolate-brown	2079.17
.13	Shale	2079.37
.20	Sandstone, very hard, fine-grained, chocolate-brown	2079.50
.23	Shale	2079.70
2.80	Sandstone, moderately hard, fine-grained, chocolate-brown	2079.93
.60	Interbedded shale and very hard sandstone, fine-grained, chocolate-brown	2082.73
.54	Sandstone, hard, fine-grained, chocolate-brown	2083.33
.10	Shale	2083.87
.92	Sandstone, very hard, fine-grained, grayish-brown	2083.97
.20	Shale	2084.89
.20	Sandstone, hard, fine-grained, chocolate-brown	2085.09
.10	Shale	2085.29
.25	Sandstone, hard, fine-grained, chocolate-brown	2085.39
.10	Shale	2085.64
.05	Sandstone, hard, fine-grained, chocolate-brown	2085.74
.10	Shale	2085.79
.05	Sandstone, hard, fine-grained, chocolate-brown	2085.89
.06	Shale	2085.94
.03	Sandstone, hard, fine-grained, chocolate-brown	2086.00
.10	Shale	2086.03
.20	Sandstone, very hard, fine-grained, chocolate-brown	2086.13
.10	Shale	2086.33
1.00	Sandstone, very hard, fine-grained, grayish-brown	2086.43
.10	Shale	2087.43
.85	Sandstone, very hard, fine-grained, grayish-brown	2087.53
.40	Shale	2088.38
1.30	Sandstone, hard, fine-grained, chocolate-brown	2088.78
2.72	Shale	2090.08
.20	Sandstone, very hard, fine-grained, grayish-brown	2092.80

Section of Core 19

.40	Limestone	2027.60
.36	Shale	2028.00
.19	Limestone	2028.36
.32	Shale	2028.55
	Top of Bradford Sand	2028.87
.80	Sandstone, very hard, fine-grained, chocolate-brown	2028.87
3.44	Sandstone, hard, fine-grained, chocolate-brown	2029.67
14.02	Sandstone, moderately hard, fine-grained, chocolate-brown	2033.11
5.44	Sandstone, friable, fine-grained, chocolate-brown	2047.13
2.00	Sandstone, moderately friable, fine-grained, chocolate-brown	2052.57
7.19	Sandstone, moderately hard, fine-grained, chocolate-brown	2054.57
.20	Shale	2061.76
2.89	Sandstone, moderately hard, fine-grained, chocolate-brown	2061.96
.40	Sandstone, very hard, fine-grained, light-gray	2064.85
.10	Shale	2065.25
3.54	Sandstone, moderately hard, fine-grained, chocolate-brown	2065.35

Core 19 Continued

Thickness feet	Description of strata	Depth to top feet
.05	Shale	2068.89
.90	Sandstone, moderately hard, fine-grained, chocolate-brown	2068.94
.70	Alternately thin laminae of shale and sandstone, fine-grained, hard, chocolate-brown	2069.84
3.59	Sandstone, moderately hard, fine-grained, chocolate-brown	2070.54
1.00	Shale	2074.13
.30	Sandstone, hard, fine-grained, chocolate-brown	2075.13
.50	Shale	2075.43
.20	Sandstone, hard, fine-grained, chocolate-brown	2075.93
.10	Shale	2076.13
.30	Sandstone, hard, fine-grained, chocolate-brown	2076.23
1.10	Shale	2076.53
.50	Sandstone, hard, fine-grained, chocolate-brown	2077.63
.20	Shale	2078.13

Section of Core 20

	Top of Bradford sand	1887.00
2.42	Sandstone, hard, fine-grained, chocolate-brown	1887.00
.33	Shale	1889.42
2.92	Sandstone, hard, fine-grained, chocolate-brown	1889.75
.08	Shale	1892,67
.08	Sandstone, hard, fine-grained, chocolate-brown	1892.75
.08	Shale	1892.83
3.09	Sandstone, hard, fine-grained, chocolate-brown	1892.91
3.00	Shale	1896.00
1.50	Sandstone, moderately hard, fine-grained, chocolate-brown	1899.00
.50	Shale	1900.50
.08	Sandstone, hard, fine-grained, chocolate-brown	1901.00
.08	Shale	1901.08
.17	Sandstone, hard, fine-grained, chocolate-brown	1901.16
.08	Shale	1901.33
.09	Sandstone, hard, fine-grained, chocolate brown	1901.41
.08	Shale	1901.50
.50	Sandstone, hard, fine-grained, chocolate-brown	1901.58
.08	Shale	1902.08
.25	Sandstone, hard, fine-grained, chocolate-brown	1902.16
.09	Shale	1902.41
1.00	Sandstone, hard, fine-grained, chocolate-brown	1902.50
.33	Shale	1903.50
6.17	Sandstone, hard, fine-grained, chocolate-brown	1903.83
1.33	Shale in part sandy	1910.00
.83	Sandstone, hard, fine-grained, grayish-brown	1911.33
.84	Shale in part sandy	1912.16
1.50	Shale	1913.00
.17	Sandstone, hard, fine-grained, grayish-brown	1914.50
2.08	Shale in part sandy	1914.67
2.00	Sandstone, moderately hard, fine-grained, chocolate-brown	1916.75
12.75	Sandy shale with some shale and numerous thin very hard seams sandstone, fine-grained, chocolate-brown	1918.75
.33	Sandstone, hard, fine-grained, chocolate-brown	1931.50
.08	Shale	1931.83
.83	Sandstone, moderately hard, fine-grained, chocolate brown	1931.91
.17	Shale	1932.74
1.09	Sandstone, hard, fine-grained, grayish-brown	1932.91
1.92	Sandy shale with some shale and numerous thin seams of sandstone, hard, fine-grained, chocolate-brown	1934.00
.17	Sandstone, hard, fine-grained, gray	1935.92

Section of Core 21

	Shale with fossiliferous seams	
.08	Sandstone, hard, very coarse, gray, with quartz pebbies up to ⅛-inch diameter, angular to subangular	1905.00
1.84	Lost	1905.08
	Top of Bradford sand	1906.00

Core 21 Continued

Thickness feet	Description of strata	Depth to top feet
2.47	Sandstone, moderately hard, very fine-grained, chocolate-brown	1906.92
.20	Shale	1909.39
5.10	Sandstone, moderately hard, very fine-grained, chocolate-brown	1909.59
.30	Sandy shale	1914.69
2.28	Shale	1914.99
1.00	Sandstone, hard, very fine-grained, chocolate-brown	1917.27
.20	Shale	1918.27
1.20	Sandstone, hard, very fine-grained, chocolate-brown	1918.47
3.40	Shale	1919.67
1.61	Sandstone, hard, fine-grained, chocolate-brown	1923.07
.23	Shale	1924.68
6.67	Sandstone, hard, very fine-grained, chocolate-brown	1924.91
2.00	Shale with numerous thin seams of sandstone, hard, fine-grained, chocolate-brown	1931.58
4.45	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1933.58
1.00	Shale with numerous thin seams of hard sandstone, fine-grained, chocolate-brown	1938.03
.70	Sandstone, hard, fine-grained, dark chocolate-brown	1939.03
.20	Shale	1939.73
.10	Sandstone, hard, fine-grained, dark chocolate-brown	1939.93
.10	Shale	1940.03
1.00	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1940.13
.05	Shale	1941.13
.25	Sandstone, moderately hard, fine-grained, dark chocolate-brown	1941.18
2.00	Sandstone, hard, fine-grained, dark chocolate-brown, with numerous thin shale seams	1941.43
.80	Sandstone, hard, fine-grained, chocolate-brown	1943.43
.60	Shale	1944.23
.15	Sandstone, hard, fine-grained, chocolate-brown	1944.83
.55	Shale with a few thin seams of hard chocolate-brown sandstone	1944.98
.60	Sandstone, hard, fine-grained, chocolate-brown	1945.53
2.80	Shale with numerous thin seams of sandstone, hard, fine-grained, chocolate-brown	1946.13
2.10	Sandstone, hard, fine-grained, chocolate-brown	1948.93
.20	Shale	1951.03
.30	Sandstone, hard, fine-grained, chocolate-brown	1951.23
.60	Shale with some thin seams of sandstone, hard, fine-grained, chocolate-brown	1951.53
.80	Shale	1952.13

The sections of Table 6 illustrate the wide variations, not only in total thickness of the sand body, but also in the number and thickness of the shale partings in the sand. The data are summarized in Table 7.

Table 7. Total thickness of Bradford Third sand and thickness and percent of oil-bearing sandstone of 10 percent or more porosity, as shown by 21 cores.

Core	Thickness of Bradford Third sand Feet	Thickness of oil-bearing sandstone Feet	Per cent of sandstone oil-bearing	Core	Thickness of Bradford Third sand Feet	Thickness of oil-bearing sandstone Feet	Per cent of sandstone oil-bearing
1	49.5	23.0	47	12	50.8	40.2	79
2	51.8	33.4	65	13	52.3	38.1	73
3	76.1	40.4	53	14	11.0	8.0	73
4	66.7	40.0	60	15	6.2	5.3	85
5	72.9	44.5	61	16	30.9	28.2	91
6	41.8	28.0	67	17	30.3	21.3	70
7	45.8	35.0	76	18	54.0	41.8	77
8	16.9	15.2	90	19	49.3	43.8	89
9	64.6	36.5	57	20	47.0	23.5	50
10	48.3	16.0	33	21	45.5	28.5	63
11	43.3	27.6	64				

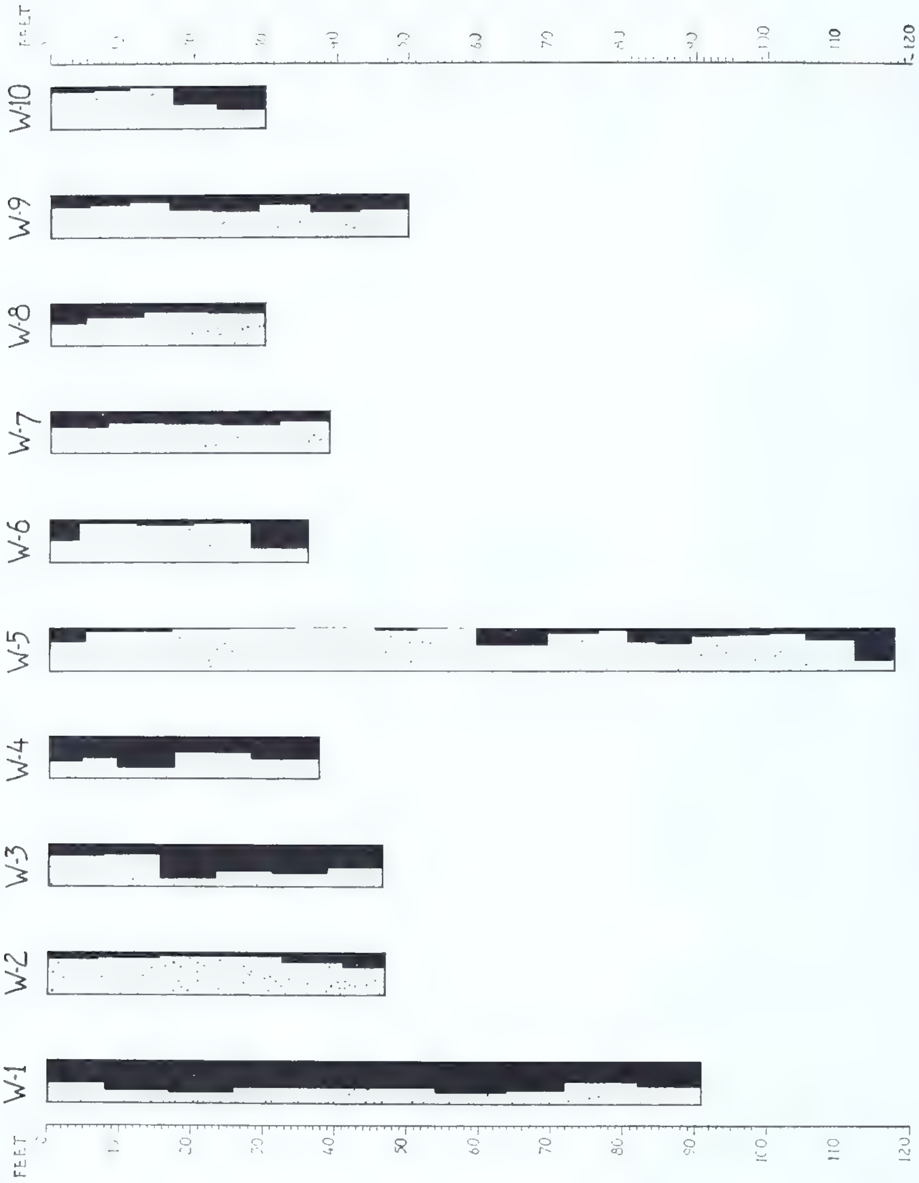


FIGURE 15. Proportions of sandstone and shale in Bradford Third sand in wells W-1 to W-10.

The data on the actual thicknesses of oil-bearing sandstone present in the Bradford Third sand, obtained from the 21 cores, were supplemented by studies of drill cuttings of the sand from 49 other wells also widely distributed over the entire district. Their locations are shown on Plate E. The sample of cuttings as received from each screw of sand drilled was reduced in volume by coning and quartering several times. A representative sample weighing between one-half and one gram, the exact amount depending upon the size of the fragments, was then selected. This was screened on a 60-mesh sieve. The undersize was considered sand. The oversize was placed on a glass plate resting upon a white background and sorted into two piles, one consisting of particles of chocolate-brown sandstone and the other of gray shale. The separation was performed by hand, using a lens of 2½ x magnification and a bent dissecting needle. The undersize and the sandstone pile were weighed together and from the data obtained the relative amounts of sandstone and shale in the screw were calculated. The results of these studies are summarized in Table 8 and shown graphically on Figures 15 to 18. In the illustrations, the dotted areas represent the proportion of sandstone and the black areas, the proportion of shale in each screw. The lengths of the individual screws are drawn to scale.

Table 8. Proportion of sandstone present in the Bradford Third sand in 49 selected wells.

(Data obtained from drill cuttings)

W-1

Top of sand 1419 feet

Screw No.	Length **Feet**	Sandstone **Feet**
1	8	3.8
2	9	2,9
3	9	2.7
4	9	3.5
5	9	3.5
6	10	3.9
7	10	3.2
8	8	2.7
9	10	5.3
10	9	3.9
Total	91	35.4

Percent sandstone 39.

W-2

Top of sand 1698 feet

Screw No.	Length **Feet**	Sandstone **Feet**
*1	7.0	5.9
2	8.5	7.2
3	8.5	7.6
4	8.5	7.6
5	8.5	6.5
6	6.0	3.7
Total	47.0	38.5

Percent sandstone 82.
*gas sand.

W-3

Top of sand 1260.5 feet

Screw No.	Length **Feet**	Sandstone **Feet**
1	7.75	5.6
2	7.75	5.8
3	7.75	1.6
4	7.75	2.8
5	7.75	2.5
6	7.75	3.5
Total	46.50	21.8

Percent sandstone 47.

W-4

Top of sand 1062 feet

Screw No.	Length **Feet**	Sandstone **Feet**
1	4.75	1.9
2	4.75	2.3
3	8.00	2.2
4	10.50	6.3
5	9.50	4.5
Total	37.50	17.2

Percent sandstone 46.

W-5

Top of sand 1140 feet

Screw No.	Length **Feet**	Sandstone **Feet**
1	5.0	3.3
2	12.0	11.1
3	8.0	7.9
4	9.0	8.9
5	5.0	5.0
6	6.0	6.0
7	6.0	5.7
8	4.0	3.9
9	4.0	4.0
Bottom of gas pay		
10	10.0	6.3
11	7.0	6.1
12	4.0	3.7
13	4.0	3.9
14	5.0	3.2
15	5.0	4.0
16	6.0	4.9
17	5.0	4.2
18	7.0	5.1
19	6.0	1.6
Total	118.0	98.8

Percent sandstone 84.

W-6

Top of sand 1080 feet

Screw No.	Length **Feet**	Sandstone **Feet**
1	4	2.0
2	8	7.2
3	8	7.1
4	8	7.2
5	8	2.8
Total	36.0	26.3

Percent sandstone 73.

W-7

Top of sand 1642 feet

Screw No.	Length **Feet**	Sandstone **Feet**
1	8	4.8
2	8	5.6
3	8	5.5
4	8	5.5
5	7	5.2
Total	39	26.6

Percent sandstone 68.

W-8

Top of sand 1740 feet

Screw No.	Length **Feet**	Sandstone **Feet**
1	5	2.5
2	8	5.3
3	9	7.1
4	8	6.3
Total	30	21.2

Percent sandstone 71.

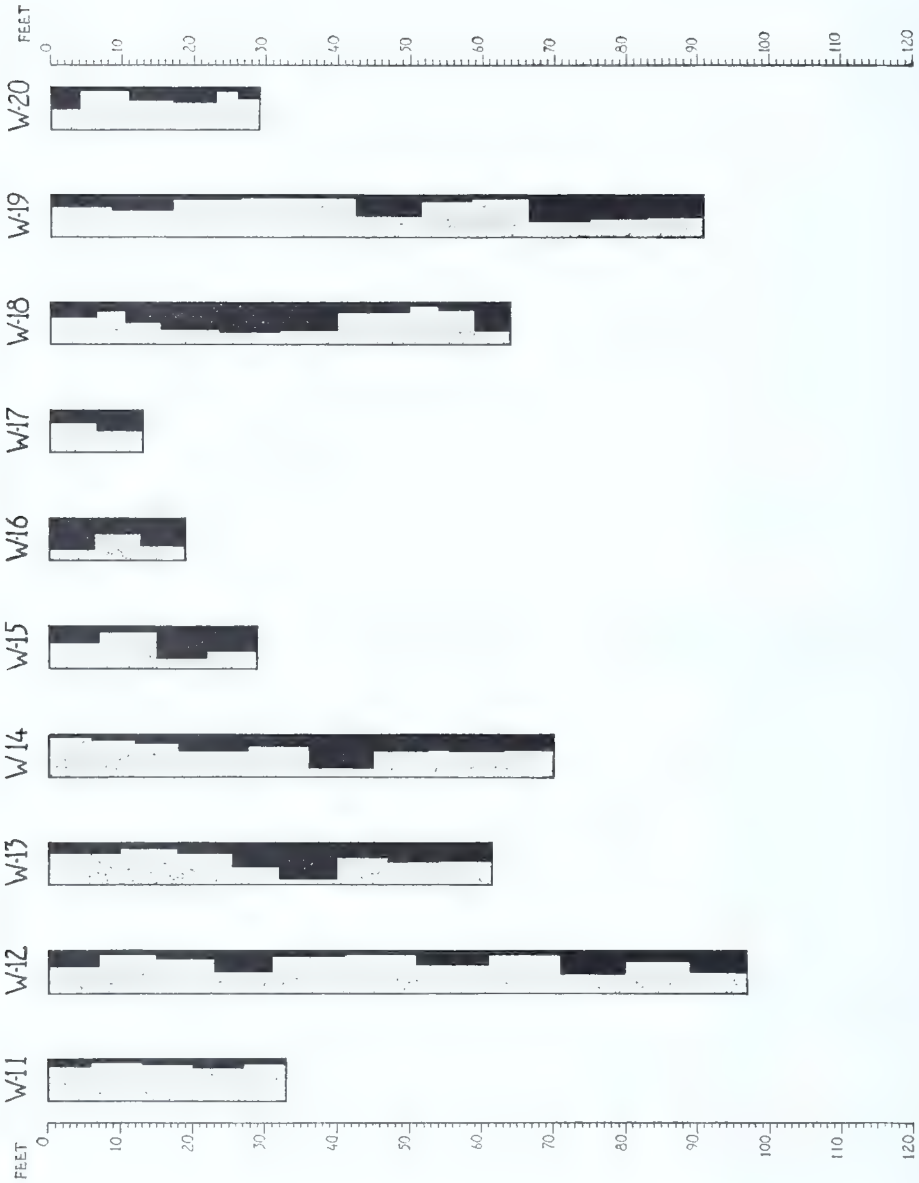


FIGURE 16. Proportions of sandstone and shale in Bradford Third sand in wells W-11 to W-20.

W-9

Top of sand 1771 feet

Screw No.	Length Feet	Sandstone Feet
1	5.5	3.9
2	5.5	4.2
3	5.5	4.6
4	6.0	3.9
5	6.5	3.9
6	7.0	5.4
7	7.0	4.1
8	7.0	4.5
Total	50.0	34.5

Percent sandstone 69.

W-10

Top of sand 1484 feet

Screw No.	Length Feet	Sandstone Feet
1	6	5.2
2	5	4.5
3	6	5.8
4	6	3.5
5	7	3.2
Total	30	22.2

Percent sandstone 74.

W-11

Top of sand .... feet

Screw No.	Length Feet	Sandstone Feet
1	6	4.8
2	7	6.3
3	7	5.9
4	7	5.5
5	6	5.2
Total	33	27.7

Percent sandstone 84.

W-12

Top of sand 1130 feet

Screw No.	Length Feet	Sandstone Feet
1	7.0	4.4
2	8.0	7.2
3	8.0	6.4
4	8.0	4.0
5	10.0	8.6
6	10.0	9.0
7	10.0	6.6
8	10.0	9.0
9	9.0	4.3
10	9.0	6.7
11	8.0	3.9
Total	97.0	70.1

Percent sandstone 72.

W-13

Top of sand 1106 feet

Screw No.	Length Feet	Sandstone Feet
1	10	8.8
2	8	7.2
3	7.5	6.5
4	6.5	3.2
5	8.0	1.2
6	7.0	5.3
7	7.0	4.5
8	7.5	4.8
Total	61.5	41.5

Percent sandstone 68.

W-14

Top of sand 1705 feet

Screw No.	Length Feet	Sandstone Feet
1	6	5.7
2	6	5.2
3	6	4.8
4	9.5	5.8
5	8.5	6.1
6	9.0	1.9
7	7.5	4.7
8	3.0	1.9
9	7.5	4.7
10	7.0	4.6
Total	70.0	45.4

Percent sandstone 65.

W-15

Top of sand 1152 feet

Screw No.	Length Feet	Sandstone Feet
1	7	4.3
2	8	6.9
3	7	1.9
4	7	2.8
Total	29	15.9

Percent sandstone 55.

W-16

Top of sand 1271 feet

Screw No.	Length Feet	Sandstone Feet
1	6.3	1.7
2	6.3	4.0
3	6.3	2.1
Total	18.9	7.8

Percent sandstone 41.

W-17

Top of sand 1246 feet

Screw No.	Length Feet	Sandstone Feet
1	6.5	4.5
2	6.5	3.3
Total	13.0	7.8

Percent sandstone 60.

W-18

Top of sand 1732 feet

Screw No.	Length Feet	Sandstone Feet
1	6.5	4.0
2	4.0	3.0
3	5.0	2.6
4	8.0	2.8
5	8.5	2.4
6	8.0	2.5
7	10.0	7.6
8	4.0	3.6
9	5.0	4.0
10	5.0	1.5
Total	64.0	34.0

Percent sandstone 53.

W-19

Top of sand 1585 feet

Screw No.	Length Feet	Sandstone Feet
1	8.5	5.9
2	8.5	5.6
3	9.5	8.5
4	8.5	7.6
5	7.5	6.3
6	9.0	4.6
7	7.0	5.9
8	8.0	7.2
9	8.5	3.3
10	8.0	3.5
11	8.0	3.7
Total	91.0	62.1

Percent sandstone 68.

W-20

Top of sand 1306 feet

Screw No.	Length Feet	Sandstone Feet
1	4	2.0
2	7	6.4
3	6	4.2
4	6	3.9
5	3	2.6
6	3	2.1
Total	29	21.2

Percent sandstone 73.

W-21

Top of sand 1163 feet

Screw No.	Length Feet	Sandstone Feet
1	6.0	5.1
2	6.0	6.0
3	6.0	4.5
4	6.0	4.5
5	6.0	2.8
Total	30.0	22.9

Percent sandstone 76.

W-22

Top of sand 1489 feet

Screw No.	Length Feet	Sandstone Feet
1	7	5.4
2	7	5.9
3	8	5.2
4	8	0.0
5	8	1.4
6	8	3.9
7	8	3.9
8	8	4.1
9	8	3.3
10	8	3.7
11	8	4.4
12	8	4.9
Total	94	46.1

Percent sandstone 49.

W-23

Top of sand 1814 feet

Screw No.	Length Feet	Sandstone Feet
1	5	4.5
2	11	7.2
3	8	4.8
Total	24	16.5

Percent sandstone 68.

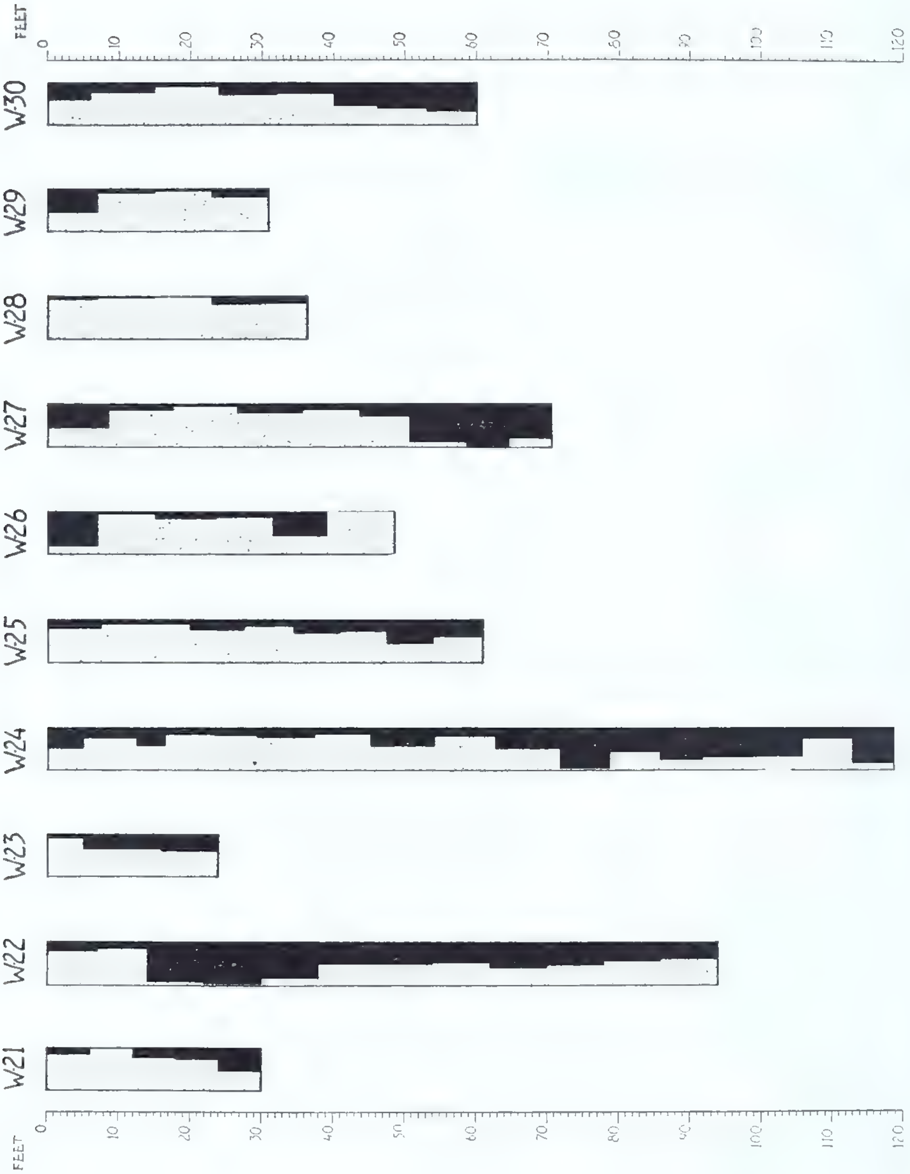


FIGURE 17. Proportions of sandstone and shale in Bradford Third sand in wells W-21 to W-30.

W-24

Top of sand 1253.5 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	5.0	2.5
2	7.5	5.6
3	4.0	2.3
4	7.0	5.8
5	6.0	4.8
6	8.0	6.1
7	8.0	6.7
8	9.0	5.1
9	8.5	6.8
10	9.0	4.5
11	7.0	0.3
12	7.0	3.1
13	6.0	1.6
14	7.0	2.1
15	7.0	2.3
16	7.0	5.2
17	6.0	1.0
Total	119.0	65.8

Percent sandstone 55.

W-25

Top of sand 1882 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	7.5	6.1
2	7.5	6.3
3	5.0	4.5
4	7.5	5.8
5	7.0	6.0
6	6.5	4.5
7	6.5	4.8
8	6.5	3.0
9	7.0	4.4
Total	61.0	45.4

Percent sandstone 74.

W26

Top of sand 1170 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	7.0	1.3
2	8.0	7.6
3	8.5	7.2
4	8.0	6.9
5	7.5	3.3
6	9.5	9.5
Total	48.5	35.8

Percent sandstone 74.

W-27

Top of sand 1178.5 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	8.5	3.7
2	9.0	7.8
3	9.0	8.6
4	9.0	7.1
5	8.0	7.0
6	7.0	5.0
7	8.0	0.8
8	6.0	0.1
9	6.0	1.0
Total	70.5	41.1

Percent sandstone 58.

W-28

Top of sand 1184 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	7	6.5
2	8	7.8
3	8	7.8
4	7	5.8
5	6.5	5.5
Total	36.5	33.4

Percent sandstone 91.

W-29

Top of sand 1112 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	7	3.0
2	8	7.2
3	8	7.5
4	8	6.3
Total	31	24.0

Percent sandstone 77.

W-30

Top of sand 1723 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	6	3.3
2	9	6.8
3	9	8.1
4	8	5.6
5	8	5.9
6	6	2.7
7	7	2.7
8	7	2.2
Total	60	37.3

Percent sandstone 62.

W-31

Top of sand 1883 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	6	4.2
2	6	4.7
3	5	4.7
4	5.5	5.2
5	6.0	5.7
6	6.0	5.7
7	6.5	4.9
8	6.0	4.3
Total	47.0	40.4

Percent sandstone 86.

W-32

Top of sand 1631 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	6	4.0
2	6	5.4
3	7	6.4
Total	19	15.8

Percent sandstone 83.

W-33

Top of sand 1514.5 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	3.0	1.8
2	6.5	5.9
3	9.0	8.6
4	6.0	4.9
Total	24.5	21.2

Percent sandstone 87.

W-34

Top of sand 1372 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	8	2.2
2	8	7.6
3	8	7.6
4	7.5	2.8
Total	31.5	20.2

Percent sandstone 64

W-35

Top of sand 1185 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	7	4.0
2	10	3.5
3	7	5.1
4	8.5	5.1
Total	32.5	17.7

Percent sandstone 54.

W-36

Top of sand 1836 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	7.0	5.1
2	7.0	6.3
3	8.0	5.9
4	8.5	5.8
5	8.0	3.0
6	8.0	4.3
Total	46.5	30.4

Percent sandstone 65.

W-37

Top of sand 1457 feet

Screw	Length	Sandstone
No.	**Feet**	**Feet**
1	8	6.5
2	8	6.5
3	8	6.7
4	8	4.8
Total	32	24.5

Percent sandstone 77.

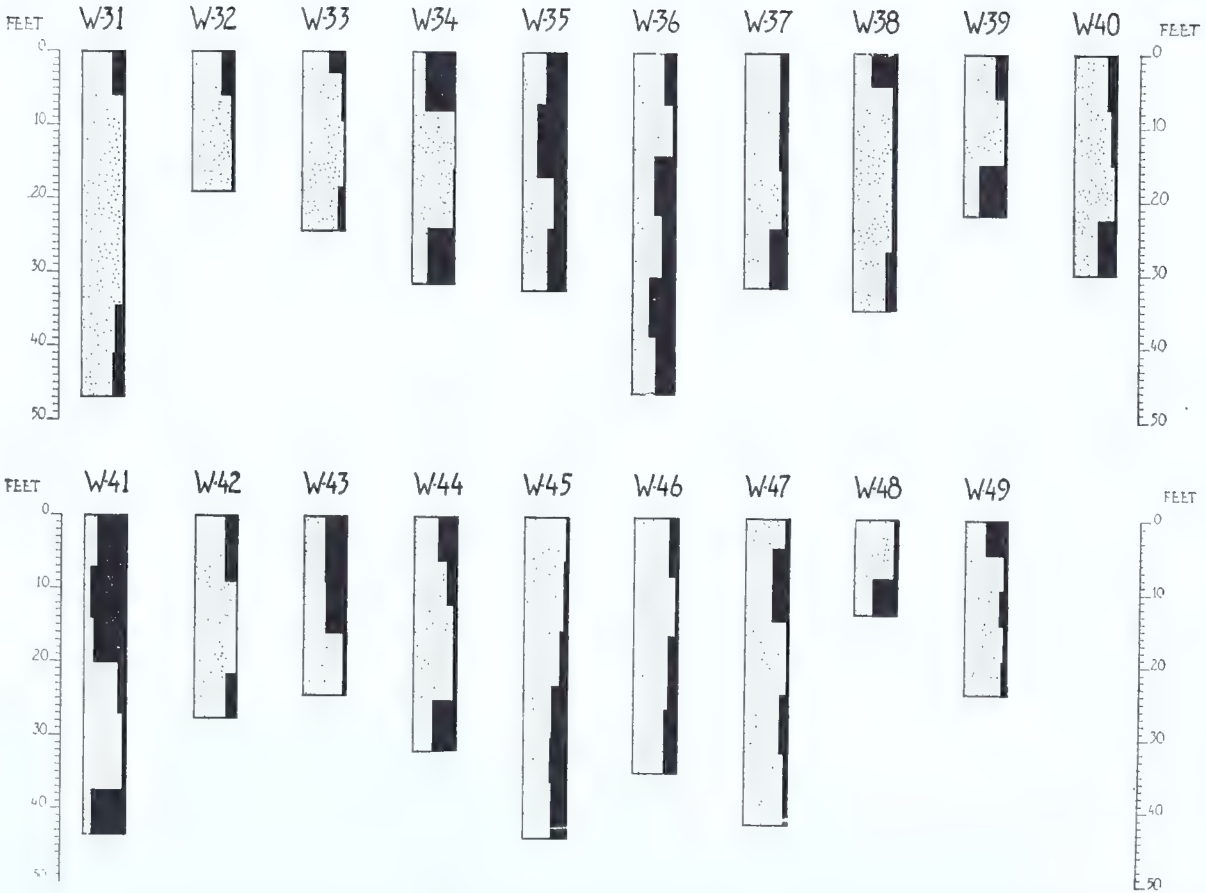
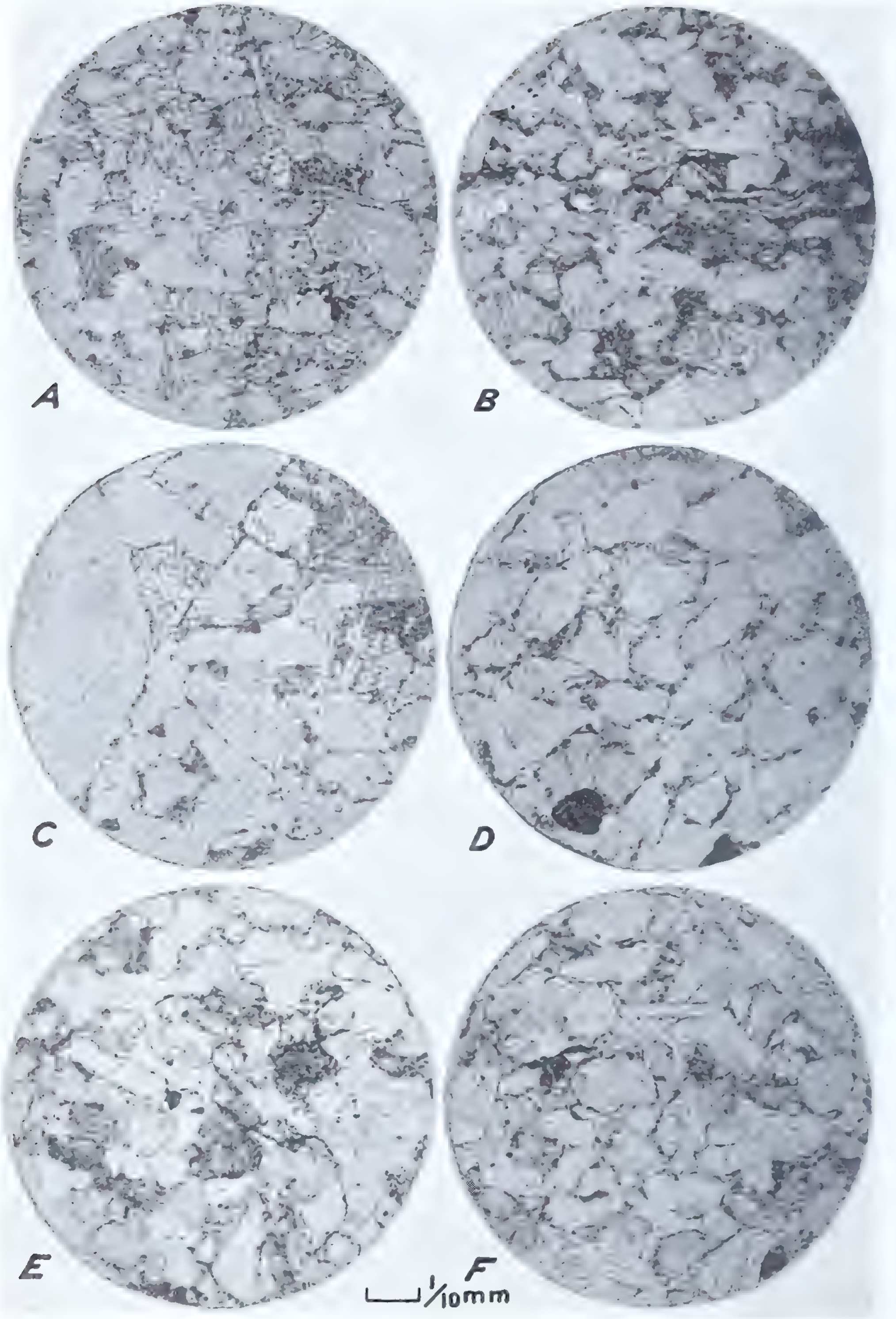


FIGURE 18. Proportions of sandstone and shale in Bradford Third sand in wells W-31 to W-49.



A. Photomicrograph of sandstone occurring at a depth of 1736.71 feet in core 9; B. At 1666.50 feet in core 11; C. At 1876.25 feet in core 1; D. At 1895.80 feet in core 1; E. At 2049.59 feet in core 19; F. At 2051.07 feet in core 19.

W-38

Top of sand 1911 feet

Screw No.	Length Feet	Sandstone Feet
1	4.5	1.8
2	7.0	6.3
3	6.5	5.8
4	9.0	8.1
5	8.0	6.2
Total	35.0	28.2

Percent sandstone 81.

W-39

Top of sand 1303 feet

Screw No.	Length Feet	Sandstone Feet
1	6	4.2
2	9	8.5
3	7	2.5
Total	22	15.2

Percent sandstone 69.

W-40

Top of sand 2040 feet

Screw No.	Length Feet	Sandstone Feet
1	7.5	5.8
2	7.5	6.5
3	7.5	7.1
4	7.5	4.2
Total	30.0	23.6

Percent sandstone 79.

W-41

Top of sand 1538 feet

Screw No.	Length Feet	Sandstone Feet
1	7	2.1
2	7	1.0
3	6	1.3
4	7	5.4
5	3.5	3.1
6	7	6.3
7	6	1.2
Total	43.5	20.4

Percent sandstone 47.

W-42

Top of sand 1529 feet

Screw No.	Length Feet	Sandstone Feet
1	9.0	6.2
2	6.0	5.7
3	6.5	6.2
4	6.0	4.3
Total	27.5	22.4

Percent sandstone 81.

W-43

Top of sand 2085 feet

Screw No.	Length Feet	Sandstone Feet
1	9.0	4.3
2	7.0	3.4
3	8.5	7.6
Total	24.5	15.3

Percent sandstone 62.

W-44

Top of sand 2012 feet

Screw No.	Length Feet	Sandstone Feet
1	6	3.3
2	6	5.7
3	6	5.4
4	7	6.3
5	7	3.0
Total	32.	23.7

Percent sandstone 74.

W-45

Top of sand 2032 feet

Screw No.	Length Feet	Sandstone Feet
1	6.0	5.7
2	9.5	8.5
3	7.5	6.2
4	7.0	4.5
5	6.0	3.8
6	8.0	5.1
Total	44.0	33.8

Percent sandstone 77.

W-46

Top of sand 2035 feet

Screw No.	Length Feet	Sandstone Feet
1	8.0	6.2
2	8.0	7.6
3	10.0	7.9
4	9.0	6.2
Total	35.0	27.9

Percent sandstone 80.

W-47

Top of sand 2038 feet

Screw No.	Length Feet	Sandstone Feet
1	4.0	3.6
2	10.0	6.4
3	10.0	9.5
4	8.0	6.3
5	10.0	9.1
Total	42.0	34.9

Percent sandstone 83.

W-48

Top of sand 1857 feet

Screw No.	Length Feet	Sandstone Feet
1	8	7.2
2	6	2.6
Total	14	9.8

Percent sandstone 70.

W-49

Top of sand 2084 feet

Screw No.	Length Feet	Sandstone Feet
1	4.8	2.3
2	4.8	4.3
3	4.8	3.9
4	4.8	4.3
5	4.8	4.0
Total	24.0	18.8

Percent sandstone 78.

Mineralogical Composition

The Bradford Third sand is a chocolate-brown sandstone composed predominantly of fine to very fine angular quartz grains. Occasionally a few well-rounded small pebbles, of transparent to milky quartz up to 3 millimeters in diameter, occur scattered through the sandstone. These are mostly in the upper layers and only rarely constitute any appreciable volume of the rock.

In thin section, the sandstone presents an interlocking mosaic of fine angular quartz grains, as shown in the photomicrographs, Plate 14. A few flakes of muscovite and biotite mica and an occasional plagioclase grain are present in nearly all thin sections. Some of the mica flakes are bent around the quartz grains. The biotite has in part been altered to chlorite. A small amount of interstitial clay, consisting of an aggregate of sericite, kaolin, and a brown mineral, possibly limonite, occurs between the quartz grains, but is not uniformly distributed. Silica, as a secondary crystalline outgrowth from the original quartz grains, and the small amount of clay mentioned, form the bond. Calcite is rarely present in large enough amount to constitute an important bonding agent. In most thin sections, only one or two grains of calcite can be seen. Occasional small clusters of minute pyrite crystals, clearly of secondary origin, are present. In sections cut perpendicular to the bedding, stratification is frequently faintly indicated by the alignment of the occasional mica flakes and some of the elongated quartz grains parallel to the bedding planes.

A thin section cut from the sandstone occurring at a depth of 1741.92 feet in core 9 has, in addition to the quartz grains, a few flakes of muscovite and biotite mica and an occasional plagioclase grain. Some of the mica flakes are bent around the quartz grains. Silica, as a secondary crystalline outgrowth from the original quartz grains, and a small amount of clay consisting of an aggregate of sericite, kaolin, and a brown mineral, possibly limonite, form the bond. Only one or two calcite grains were observed. Occasional clusters of minute pyrite crystals of secondary origin are present. A separation with bromoform yielded only 0.34 percent of heavy mineral grains, about 70 percent of which are pyrite; 15 percent of a colorless mineral, probably a pyroxene; 10 percent of zircon; and 5 percent of tourmaline. Only a few calcite grains occur in the concentrate. Many of the zircon grains show crystal outlines, although usually these are at least partly rounded. The tourmaline occurs as partly rounded prismatic grains. In the section perpendicular to the bedding, stratification is faintly indicated by the alignment of the occasional mica flakes and some of the elongated quartz grains parallel to the bedding plane.

The sandstone from which this section was prepared has a porosity of 15.7 percent. Only 1.42 feet above the point where this sample was taken —at 1740.5 feet, in the same stratum—the porosity is only 8.9 percent. Examination of a thin section from this horizon revealed abundant calcite rather uniformly deposited between the quartz grains. The porosity 0.42 feet above this is 14.4 percent. The deposition of calcite is confined to a thin seam in what otherwise appears to be a uniform stratum.

A thin section from the sandstone with a porosity of 10.1 percent, occurring at a depth of 1761.88 feet near the top of a stratum 2.33 feet thick, was found to contain more muscovite and biotite than the other sections examined and considerably more of the interstitial clay. Calcite is sparingly present at this horizon. Another section, from a thin seam with a porosity of only 6.5 percent at a depth of 1766.5 feet, shows considerably more silica deposited as a secondary crystalline outgrowth from the original quartz grains than the other sections. Some cryptocrystalline silica, probably also of secondary origin, is present. The clay content is small.

Just above the Bradford Third sand, in places separated from it by a few inches of shale, usually there are present one or more thin beds of fine-grained gray calcareous sandstone which contain an abundance of marine shells. Marine fossils are very sparingly distributed throughout the main body of the sand in many parts of the field. Fragments of carbonized plant remains are also present. Although these are probably of land origin, their fragmentary nature indicates that they were transported to their present environment by stream and wave currents.

Chemical Composition

A chemical analysis of the sandstone occurring at the depth of 1741.92 feet in core 9 was made according to the methods recommended by Washington.[23] The sample was first crushed to pass through a 100-mesh sieve, then extracted with carbon tetrachloride followed by petroleum ether, and dried at 130° C. The results are shown in Table 9.

Table 9. Chemical analysis of Bradford Third sandstone from a depth of 1741.92 feet in core 9.

	Percent		Percent
SiO_2	86.89	Alkalies	Not determ.
Al_2O_3	6.95	H_2O (combined)	0.89
Fe_2O_3 (includes FeO)	2.55	CO_2	trace
MgO	0.42	C (organic)	0.30
CaO	0.07		
			98.07

Organic carbon was determined in a combustion furnace. The presence of 0.3 percent organic carbon seems to indicate that not all the petroleum residues were removed by the extraction with carbon tetrachloride and petroleum ether. The sample analyzed was carefully examined for carbonized plant remains, such as sometimes occur in the Bradford sand, before it was crushed. None were observed.

Texture

Actual size, distribution of the various sizes, and shape of the grains of sand are characteristics of a sandstone that have an important bearing on porosity, permeability, and other properties affecting oil recovery.

The distribution of the various grain sizes is determined by a screen analysis. For making such analyses, representative fragments of the sandstone must be carefully disintegrated into their separate grains with as little breaking of the individual grains themselves as possible, a rather difficult task in the case of tightly cemented samples, but easily accomplished with loosely cemented ones.

The procedure adopted with the Bradford Third sand was to select a representative sample from the stratum to be tested, weighing approximately 12 grams. This was extracted with carbon tetrachloride for three or more hours and dried at 105° C for one hour. It was then broken into a number of fragments by tapping with an iron pestle in an iron mortar. The fragments were poured onto the uppermost one of a series of sieves arranged in order with the coarsest at the top. The particles left on the top sieve were again broken until all had passed through this sieve or had been reduced to individual grain size. This further breaking was performed in a porcelain mortar with a porcelain pestle. A gentle tapping motion, never a grinding action, was employed. When the fragments commenced to approximate individual grain dimensions, the bottom of the mortar was lined with lead foil. The same procedure was then followed on the next finer sieve and so on until the 100-mesh was reached. As a rule, all material that passed through the 100-mesh sieve had been reduced to individual grain size. A binocular microscope was used in each case to determine whether individual grain size had been reached in the case of the material remaining on a screen. Using this method on Bradford Third sand, tests on duplicate samples were found to check in most instances with ± 1 percent and almost always within ± 2 percent. After the sample had been reduced to individual grain size, it was extracted a second time with carbon tetrachloride and dried.

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[23] Henry S. Washington, The Chemical Analysis of Rocks, second edition, New York, 1910.

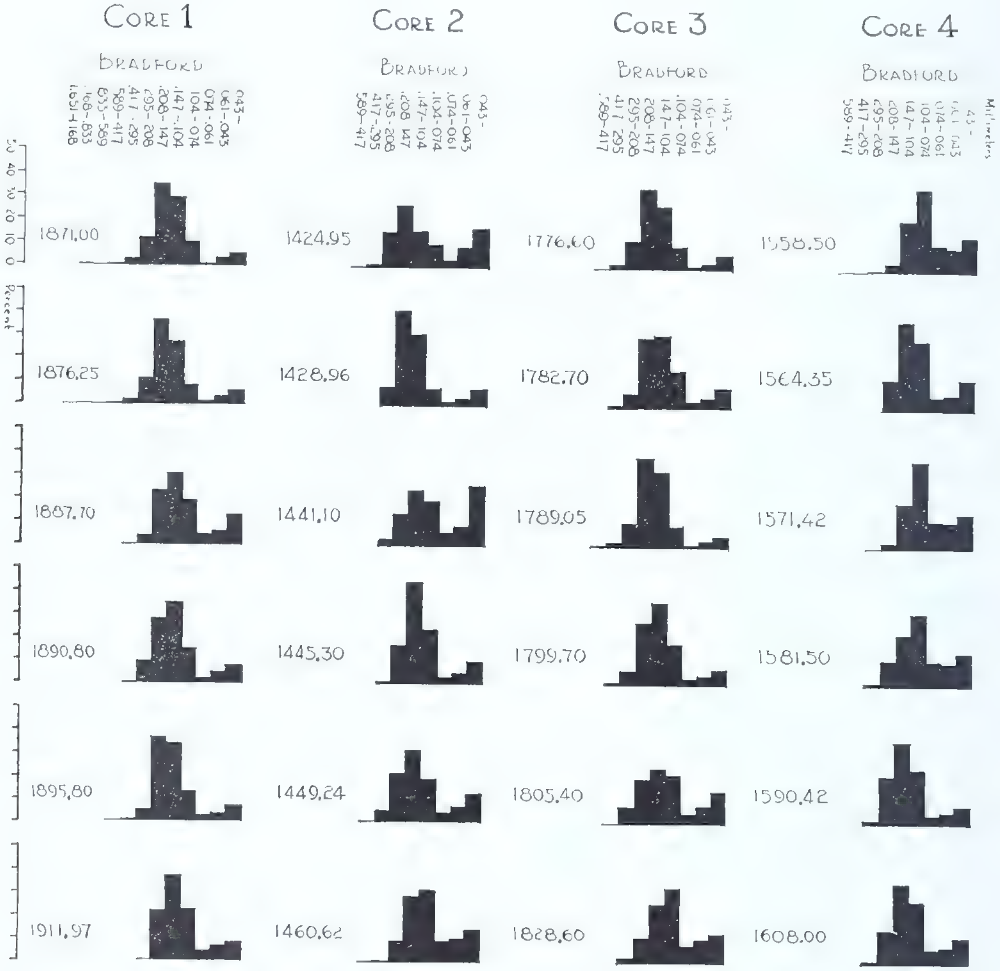

FIGURE 19. Screen analyses of Bradford Third sand from cores 1, 2, 3, and 4.

For making the screen analyses, a set of Tyler standard screen scale testing sieves was used. The 200-mesh with an opening of .074 millimeters is the finest sieve in this scale and the openings increase from this in the ratio of the square root of 2. Inasmuch as the Bradford Third sand has a considerable percentage of grains that will pass through a 200-mesh sieve, 250 and 325-mesh sieves were added to the series.

Screen analyses of representative samples from different horizons in 19 of the 21 cores described are given in Tables 10 to 28, inclusive, and are illustrated by histograms in Figures 19 to 23, inclusive. Screen analyses of five samples from a core of the Richburg sand taken in the Richburg pool in Allegany County, New York, shown in Table 29, have been included for comparison.

Table 10. Screen analyses of six samples of Bradford Third sand from core No. 1.

Size of openings millimeters		Depth in feet					
		1871.00	1876.25	1887.70	1890.80	1895.80	1911.97
Through	On	Percent					
1.651	1.168	0.0	0.2	0.0	0.0	0.0	0.0
1.168	.833	0.2	0.7	0.0	0.0	0.0	0.0
.833	.589	0.1	0.2	0.0	0.0	0.0	0.0
.589	.417	0.7	0.6	0.0	0.0	0.1	0.0
.417	.295	2.4	2.4	0.1	0.1	0.5	0.0
.295	.208	12.2	11.5	3.7	9.0	5.0	2.0
.208	.147	35.1	36.6	23.0	27.6	36.2	20.7
.147	.104	29.2	27.6	30.8	34.1	33.7	36.6
.104	.074	10.3	8.7	19.3	14.7	12.8	22.2
.074	.061	1.5	1.9	4.4	2.3	2.2	4.5
.061	.043	3.3	3.5	5.7	4.5	3.2	6.1
.043		5.1	6.1	13.0	7.6	6.3	7.8
Average grain diameter—millimeters		.056	.053	.042	.050	.053	.049
Porosity percent....		17.7	16.5	12.1	14.7	15.0	16.1

Table 11. Screen analyses of six samples of Bradford Third sand from core No. 2.

Size of openings millimeters		Depth in feet					
		1424.95	1428.96	1441.10	1445.30	1449.24	1460.62
Through	On	Percent					
.589	.417	0.1	0.0	0.0	0.0	0.0	0.0
.417	.295	1.2	0.0	0.0	0.0	0.1	0.1
.295	.208	15.3	8.0	2.3	0.6	5.2	0.2
.208	.147	27.5	41.0	14.2	15.2	21.4	8.8
.147	.104	16.6	30.8	24.6	44.3	31.3	27.8
.104	.074	10.6	7.7	18.9	23.2	18.8	30.6
.074	.061	3.0	1.9	5.5	3.5	4.1	9.1
.061	.043	8.1	3.3	8.5	4.5	6.4	9.3
.043		17.5	7.2	26.0	9.0	12.7	14.1
Average grain diameter—millimeters		.039	.051	.033	.047	.042	.041
Porosity percent....		3.8	15.7	2.0	15.7	15.2	13.3

Table 12. Screen analyses of six samples of Bradford Third sand from core No. 3.

Size of openings millimeters		Depth in feet					
		1776.60	1782.70	1789.05	1799.70	1805.40	1828.60
Through	On	Percent					
.589	.417	0.3	0.0	0.2	0.0	0.0	0.0
.417	.295	2.2	0.7	1.2	0.2	0.1	0.0
.295	.208	13.0	5.9	10.3	6.3	7.8	1.4
.208	.147	35.2	30.4	38.3	27.1	19.9	11.0
.147	.104	27.9	31.1	32.7	35.9	24.1	25.9
.104	.074	9.9	16.3	9.0	17.3	21.2	32.6
.074	.061	2.1	3.3	1.7	2.9	4.6	7.2
.061	.043	2.9	4.1	2.1	3.8	7.8	9.3
.043		6.4	8.2	4.6	6.6	14.5	12.5
Average grain diameter—millimeters		.053	.049	.057	.052	.041	.042
Porosity percent....		17.1	16.5	17.8	17.7	14.3	13.7

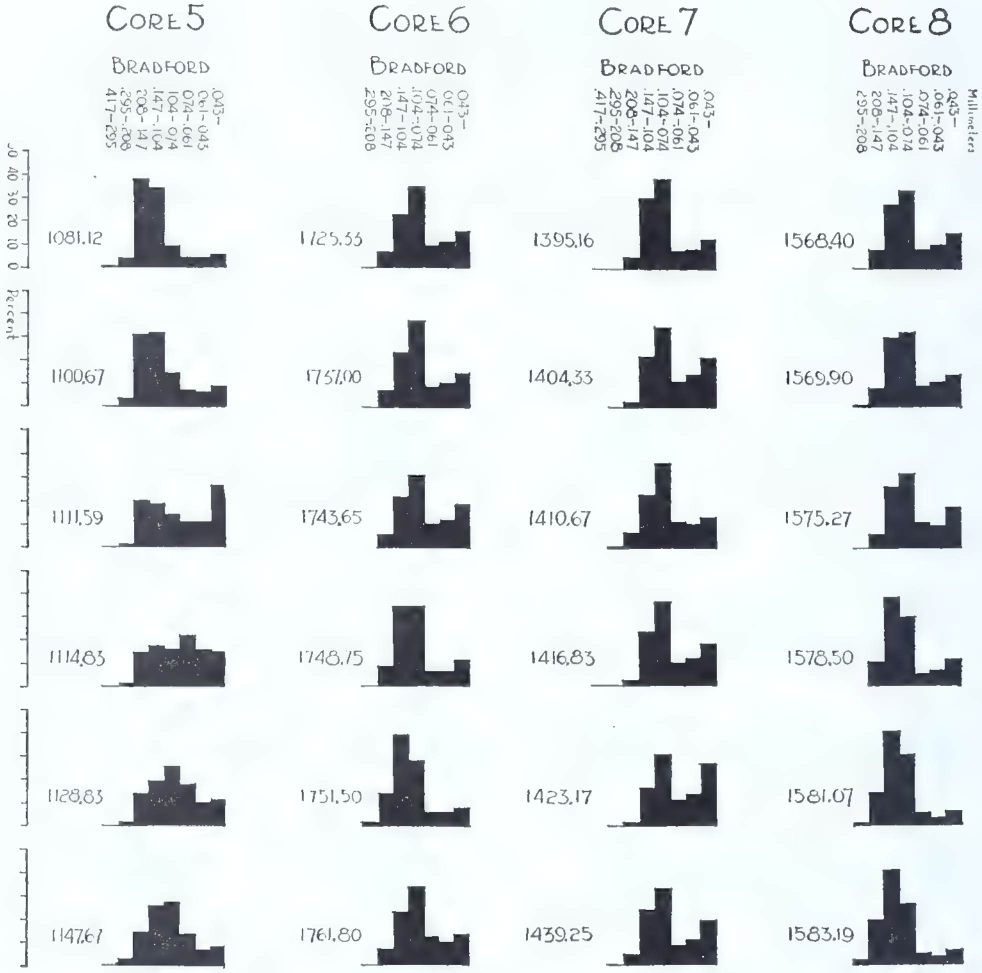

Figure 20. Screen analyses of Bradford Third sand from cores 5, 6, 7, and 8.

Table 13. Screen analyses of six samples of Bradford Third sand from core No. 4.

Size of openings millimeters		Depth in feet 1558.50	1564.35	1571.42	1581.50	1590.42	1608.00
Through	On	Percent					
.589	.417	0.1	0.0	0.0	0.0	0.0	0.0
.417	.295	0.1	0.0	0.0	0.0	0.0	0.0
.295	.208	0.3	0.1	0.1	0.9	2.1	0.7
.208	.147	3.7	8.0	2.4	11.4	21.0	13.8
.147	.104	22.2	37.6	19.9	22.4	35.7	34.4
.104	.074	36.3	29.6	37.5	31.1	23.7	26.7
.074	.061	12.1	5.8	12.5	10.3	4.1	6.7
.061	.043	10.5	6.1	12.4	9.7	5.0	7.1
.043		14.8	12.6	15.1	14.2	8.3	10.6
Average grain diameter—millimeters		.040	.042	.040	.041	.048	.045
Porosity percent....		15.0	16.8	15.6	14.6	17.9	14.9

Table 14. Screen analyses of six samples of Bradford Third sand from core No. 5.

Size of openings		Depth in feet					
millimeters		1081.12	1100.67	1111.59	1114.83	1128.83	1147.67
Through	On	Percent					
.417	.295	0.4	0.2	0.1	0.1	0.4	0.2
.295	.208	3.7	3.0	0.7	0.6	1.6	2.9
.208	.147	38.0	30.3	19.3	15.1	14.4	14.5
.147	.104	34.0	30.9	18.3	16.7	19.3	26.6
.104	.074	9.0	13.9	13.5	16.4	25.1	27.2
.074	.061	4.7	7.0	10.9	21.2	18.0	13.8
.061	.043	4.8	6.7	10.9	15.4	10.6	7.0
.043		5.5	8.0	26.4	14.4	10.8	7.7
Average grain diameter—millimeters		.055	.049	.034	.040	.044	.048
Porosity percent....		15.9	13.5	2.8	13.9	14.5	18.4

Table 15. Screen analyses of six samples of Bradford Third sand from core No. 6.

Size of openings		Depth in feet					
millimeters		1725.33	1737.00	1743.65	1748.75	1751.50	1761.80
Through	On	Percent					
.295	.208	0.1	0.3	0.0	0.3	1.2	0.3
.208	.147	4.5	7.3	5.2	8.5	14.0	6.6
.147	.104	23.6	23.3	21.9	33.7	38.8	23.4
.104	.074	34.8	36.5	31.0	33.8	28.7	33.9
.074	.061	9.8	8.4	11.1	6.2	4.7	12.2
.061	.043	11.1	9.7	12.2	6.5	4.8	10.4
.043		16.1	14.4	18.6	11.0	7.8	13.1
Average grain diameter—millimeters		.038	.040	.035	.044	.049	.040
Porosity percent......		15.0	14.2	12.6	14.7	15.5	15.8

Table 16. Screen analyses of six samples of Bradford Third sand from core No. 7.

Size of openings		Depth in feet					
millimeters		1395.16	1404.33	1410.67	1416.83	1423.17	1439.25
Through	On	Percent					
.417	.295	0.1	0.0	0.0	0.1	0.0	0.0
.295	.208	0.3	0.2	0.7	0.4	0.1	0.2
.208	.147	4.3	1.1	7.0	2.1	1.1	3.6
.147	.104	29.6	20.9	23.1	22.9	16.4	24.4
.104	.074	37.8	33.9	36.3	35.7	30.5	33.0
.074	.061	7.6	9.6	10.3	10.1	11.4	8.5
.061	.043	7.8	13.6	9.6	11.1	14.8	11.4
.043		12.5	20.7	12.9	17.7	25.6	19.0
Average grain diameter—millimeters		.042	.036	.042	.038	.034	.037
Porosity percent....		12.1	12.6	15.3	14.6	11.7	14.0

Table 17. Screen analyses of six samples of Bradford Third sand from core No. 8.

Size of openings		Depth in feet					
millimeters		1568,40	1569.90	1575.27	1578.50	1581.07	1583.19
Through	On	Percent					
.589	.417	0.0	0.0	0.0	0.0	0.0	0.0
.417	.295	0.0	0.0	0.0	0.0	0.0	0.0
.295	.208	0.1	0.3	0.1	0.2	0.9	1.9
.208	.147	7.3	7.5	4.8	10.1	14.1	18.9
.147	.104	27.3	29.3	26.3	37.8	39.7	40.0
.104	.074	32.7	30.9	31.5	29.1	30.1	25.9
.074	.061	8.1	8.5	10.2	5.5	5.1	4.1
.061	.043	9.9	10.4	9.6	6.2	3.5	3.3
.043		14.5	13.1	17.4	11.1	6.5	5.9
Average grain diameter—millimeters		.040	.041	.038	.044	.052	.053
Porosity percent....		14.6	14.3	14.2	18.6	20.7	20.2

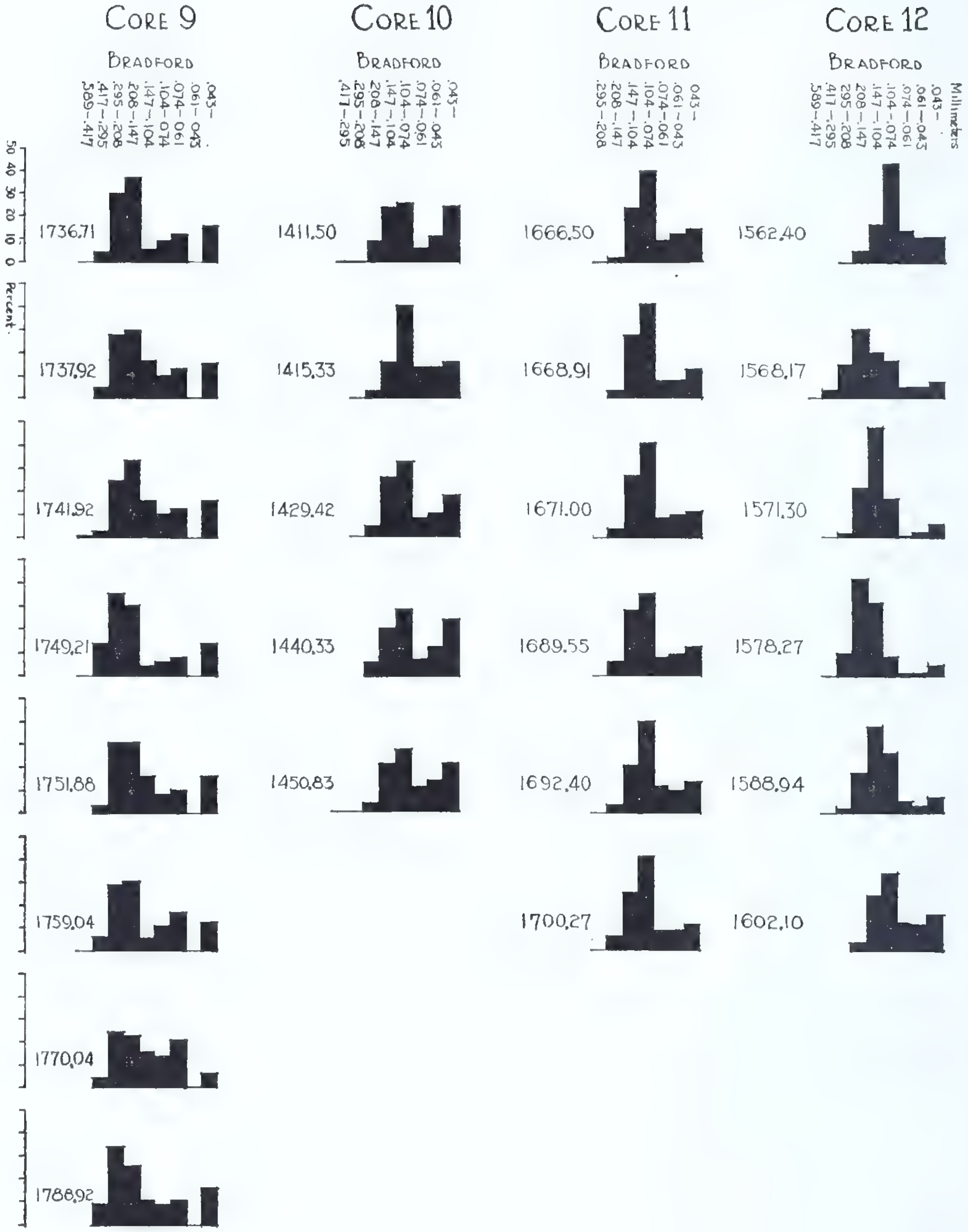

FIGURE 21. Screen analyses of Bradford Third sand from cores 9, 10, 11, and 12.

Table 18. Screen analyses of eight samples of Bradford Third sand from core No. 9.

Size openings millimeters		Depth in feet							
		1736.71	1737.92	1741.92	1749.21	1751.88	1759.04	1770.04	1788.92
Thru	On	Percent							
.295	.208	0.1	0.0	0.6	0.5	0.0	0.1	0.0	0.0
.208	.147	4.8	4.4	2.9	14.4	3.3	6.4	4.0	8.7
.147	.104	30.2	27.4	25.3	36.3	31.1	29.1	24.6	33.9
.104	.074	37.5	29.4	33.4	30.2	31.0	29.9	22.3	26.1
.074	.061	6.3	16.1	16.1	4.4	16.6	6.4	14.9	11.2
.061	.043	8.7	9.8	9.9	5.9	8.5	11.3	13.6	9.3
.043		12.4	12.8	12.7	8.2	9.5	16.8	20.5	10.9
Average grain diameter—millimeters......		.042	.042	.042	.048	.045	.039	.036	.044
Poros. percent		16.3	14.8	15.7	15.2	15.5	13.1	6.0	15.3

Table 19. Screen analyses of five samples of Bradford Third sand from core No. 10.

Size of openings millimeters...................		Depth in feet				
		1411.50	1415.33	1429.42	1440.33	1450.83
Through	On	Percent				
.417	.295	0.1	0.0	0.0	0.0	0.1
.295	.208	0.2	0.1	0.1	0.1	0.2
.208	147	8.8	3.1	5.0	5.7	3.8
.147	.104	23.0	15.4	25.4	20.5	21.3
.104	.074	25.5	39.6	32,7	28.6	27.7
.074	.061	6.7	13.1	8.4	8.0	10.6
.061	.043	11.5	13.3	10.5	12.3	14.9
.043		24.3	15.3	17.9	24.7	21.4
Average grain diameter—millimeters....		.034	.036	.035	.036	.036
Porosity percent......		11.8	15.2	14.2	7.8	12.0

Table 20. Screen analyses of six samples of Bradford Third sand from core No. 11.

Size of openings millimeters...........		Depth in feet					
		1666.50	1668.91	1671.00	1689.55	1692.40	1700.27
Through	On	Percent					
.295	.208	0.1	0.0	0.1	0.1	0.2	0.4
.208	.147	1.2	3.0	3.1	5.5	3.7	6.2
.147	.104	23.7	27.6	26.6	29.3	21.0	25.2
.104	.074	39.6	41.1	41.2	35.1	39.9	40.6
.074	.061	9.2	7.8	8.3	8.4	11.9	8.4
.061	.043	12.4	7.7	9.5	9.3	10.3	8.5
.043		13.8	12.7	11.1	12.1	12.9	10.7
Average grain diameter—millimeters..		.041	.042	.043	.042	.042	.044
Porosity percent........		15.3	12.1	15.0	14.3	12.8	14.3

Table 21. Screen analyses of six samples of Bradford Third sand from core No. 12.

Size of openings millimeters...........		Depth in feet					
		1562.40	1568.17	1571.30	1578.27	1588.94	1602.10
Through	On	Percent					
.589	.417	0.0	0.3	0.0	0.0	0.0	0.0
.417	.295	0.0	2.7	0.1	0.2	0.2	0.0
.295	.208	0.4	14.1	1.7	9.4	1.9	0.0
.208	.147	4.1	30.3	21.6	42.4	17.5	3.4
.147	.104	16.4	20.5	48.5	32.6	38.1	24.4
.104	.074	42.9	16.2	17.5	8.7	26.3	34.2
.074	.061	14.4	4.4	1.9	1.3	5.0	11.3
.061	.043	10.8	4.8	2.4	1.4	3.9	10.7
.043		10.9	6.6	6.2	4.0	7.1	15.9
Average grain diameter—millimeters..		.043	.052	.056	.062	.050	.039
Porosity percent........		16.0	17.0	22.6	24.3	20.9	13.3

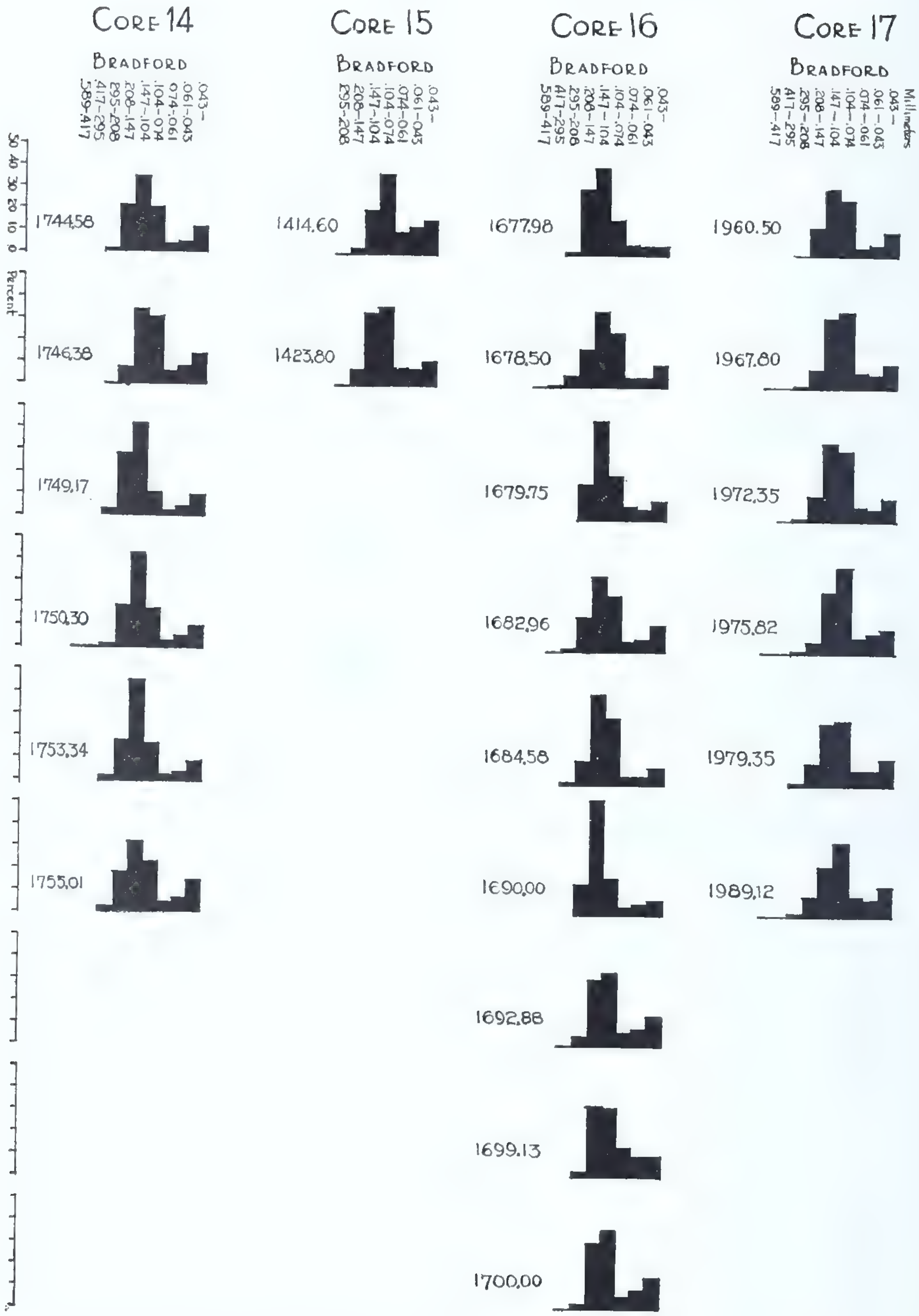

Figure 22. Screen analyses of Bradford Third sand from cores 14, 15, 16, and 17.

Table 22. Screen analyses of six samples of Bradford Third sand from core No. 14.

Size of openings millimeters............		Depth in feet 1744.58	1746.38	1749.17	1750.30	1753.34	1755.01
Through	On	Percent					
.589	.417	0.0	0.0	0.0	0.1	0.0	0.0
.417	.295	0.0	0.0	0.0	0.0	0.0	0.0
.295	.208	1.3	0.2	3.2	1.1	1.5	1.8
.208	.147	21.6	7.7	29.0	19.1	18.4	18.5
.147	.104	34.0	34.3	41.8	43.5	46.4	32.4
.104	.074	20.7	30.1	11.3	18.7	17.5	22.9
.074	.061	4.6	5.6	2.0	3.1	2.8	3.8
.061	.043	5.4	8.0	3.7	4.7	4.1	6.0
.043		12.3	14.2	9.0	9.8	9.4	14.7
Average grain diameter—millimeters..		.043	.041	.048	.046	.047	.041
Porosity percent........		15.1	14.7	15.1	13.8	15.4	11.9

Table 23. Screen analyses of two samples of Bradford Third sand from core No. 15.

Size of openings millimeters		Depth 1414.60 ft.	Depth 1423.80 ft.
Through	On	Percent	Percent
.295	.208	0.1	0.3
.208	.147	2.4	7.2
.147	.104	21.0	30.3
.104	.074	37.0	35.7
.074	.061	11.2	7.9
.061	.043	12.6	7.2
.043		15.8	11.4
Average grain diameter—millimeters..		.039	.043
Porosity percent........		16.3	15.9

Table 24. Screen analyses of nine samples of Bradford Third sand from core No. 16.

Size of openings millimeters		Depth in feet 1677.98	1678.50	1679.75	1682.96	1684.58	1690.00	1692.88	1699.13	1700.00
Through	On	Percent								
.589	.417	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
.417	.295	0.0	1.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
.295	.208	1.3	4.5	0.0	1.8	0.7	0.0	0.2	0.0	0.1
.208	.147	29.9	17.2	15.9	15.5	11.2	13.9	4.1	2.7	2.7
.147	.104	39.9	34.5	45.2	34.7	41.7	53.1	31.5	32.5	31.2
104	.074	16.6	24.8	20.3	25.7	30.5	17.0	34.4	31.9	36.2
.074	.061	4.4	3.8	5.9	4.9	4.3	4.4	6.8	13.7	6.5
.061	.043	3.8	4.4	4.6	5.6	4.0	5.3	8.6	9.4	9.0
.043		3.9	9.5	8.1	11.7	7.5	6.5	14.3	9.7	14.3
Average grain diameter—millimeters......		.061	.046	.049	.043	.050	.052	.041	.045	.041
Poros. percent		22.7	21.6	21.8	16.8	20.2	21.6	14.5	15.1	10.8

Table 25. Screen analyses of six samples of Bradford Third sand from core No. 17.

Size of openings millimeters............		Depth in feet 1960.50	1967.80	1972.35	1975.82	1979.35	1989.12
Through	On	Percent					
.589	.417	0.0	0.1	0.0	0.1	0.0	0.1
.417	.295	0.0	0.1	0.1	0.0	0.0	0.1
.295	.208	1.0	0.6	0.6	0.3	1.1	1.2
.208	.147	13.4	8.3	11.0	5.3	11.1	9.7
.147	.104	38.0	32.3	35.0	28.2	29.7	23.6
.104	.074	25.5	34.2	31.6	39.4	30.5	34.2
.074	.061	4.7	7.2	5.9	7.4	7.4	9.0
.061	.043	6.7	6.5	6.2	9.0	7.4	7.9
.043		10.6	10.8	9.6	10.2	12.8	14.2
Average grain diameter—millimeters		.045	.044	.046	.045	.042	.041
Porosity percent........		15.7	14.8	15.1	16.0	14.9	13.8

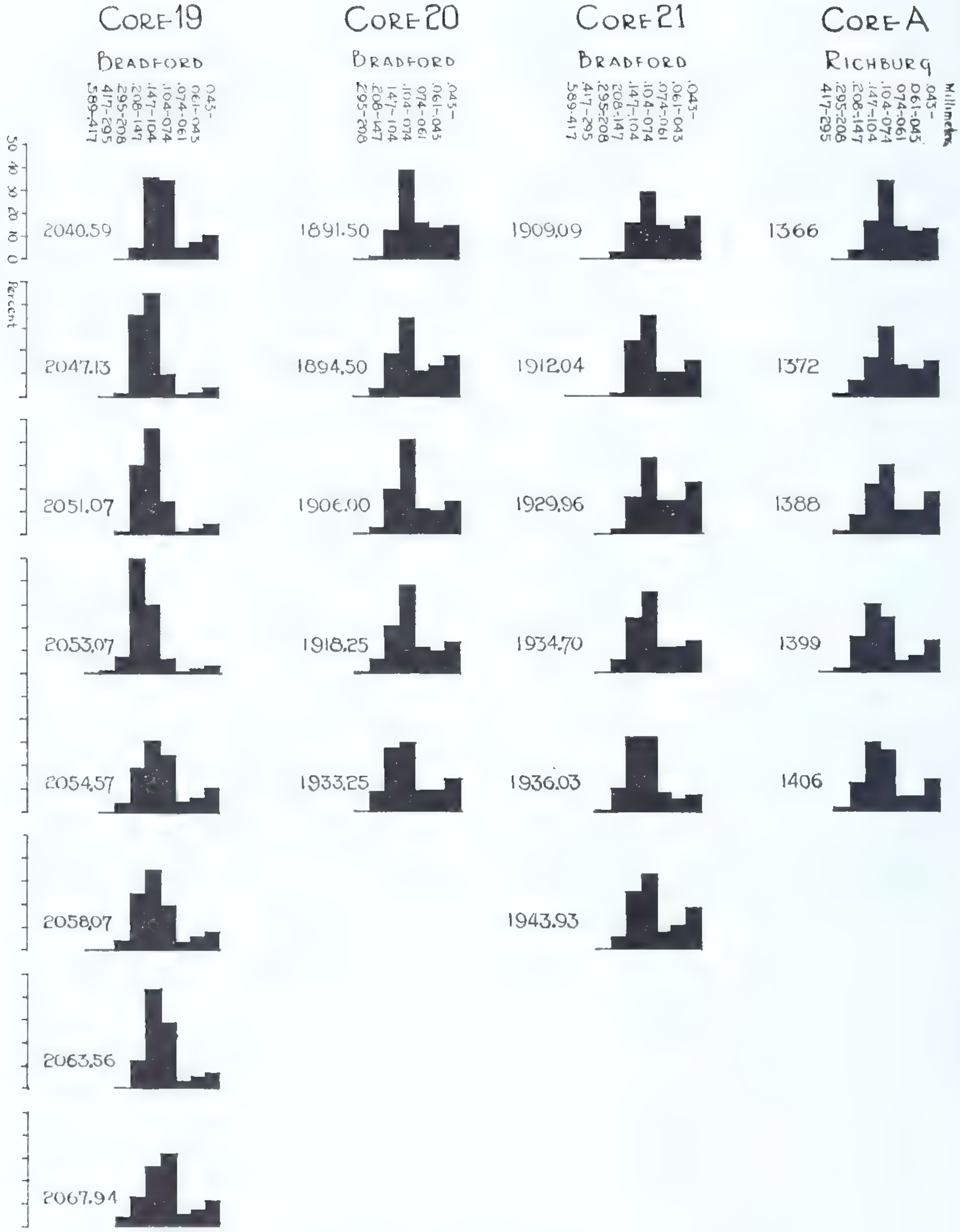

FIGURE 23. Screen analyses of Bradford Third sand from cores 19, 20, and 21, and Richburg sand from Richburg pool, N. Y.

Table 26. Screen analyses of eight samples of Bradford Third sand from core No. 19.

Size of openings millimeters		Depth in feet							
		2040.59	2047.13	2051.07	2053.07	2054.57	2058.07	2063.56	2067.04
Through	On	Percent							
.589	.417	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0
.417	.295	0.0	0.1	0.0	0.5	0.1	0.1	0.0	0.0
.295	.208	0.1	1.9	0.9	7.7	3.9	3.5	0.1	3.2
.208	.147	5.5	35.9	30.5	50.3	19.5	24.7	12.0	13.8
.147	.104	36.1	45.6	47.1	30.1	31.1	35.4	43.8	26.5
.104	.074	35.4	10.2	14.1	6.3	24.9	20.3	29.2	32.1
.074	.061	5.2	1.2	1.3	0.8	4.5	3.3	3.2	6.4
.061	.043	7.3	1.8	2.0	1.5	6.0	5.6	4.8	7.0
.043		10.4	3.1	3.9	2.6	9.8	7.1	6.7	10.9
Average grain diameter—millimeters......		.044	.066	.061	.070	.046	.051	.052	.044
Poros. percent		13.4	23.3	21.7	22.7	16.8	15.1	16.2	15.5

Table 27. Screen analyses of five samples of Bradford Third sand from core No. 20.

Size of openings millimeters....................		Depth in feet				
		1891.50	1894.50	1906.00	1918.25	1933.25
Through	On	Percent				
.295	.208	0.1	0.1	0.2	0.5	0.6
.208	.147	0.8	3.1	2.7	6.2	9.0
.147	.104	13.2	19.0	19.6	20.4	28.1
.104	.074	39.0	35.2	41.8	38.3	30.6
.074	.061	17.5	11.3	11.1	11.8	8.9
.061	.043	14.5	13.5	10.6	9.4	8.8
.043		14.9	17.7	13.9	13.4	13.9
Average grain diameter—millimeters........		.038	.038	.041	.041	.041
Porosity percent........		14.7	13.0	15.7	15.2	14.0

Table 28. Screen analyses of six samples of Bradford Third sand from core No. 21.

Size of openings millimeters............		Depth in feet					
		1909.09	1912.04	1929.96	1934.70	1936.03	1943.93
Through	On	Percent					
.589	.417	0.0	0.1	0.0	0.0	0.0	0.0
.417	.295	0.1	0.0	0.0	0.0	0.0	0.0
.295	.208	0.2	0.1	0.1	0.1	0.9	0.2
.208	.147	2.9	1.7	2.0	5.1	10.8	5.3
.147	.104	16.7	24.5	15.7	24.5	33.0	25.5
.104	.074	30.6	36.6	32.8	35.0	33.3	32.7
.074	.061	15.7	10.0	13.7	10.9	8.3	7.6
.061	.043	14.6	10.4	14.1	10.6	6.3	10.1
.043		19.1	16.4	21.7	13.6	7.3	18.5
Average grain diameter—millimeters....		.037	.039	.035	.041	.049	.037
Porosity percent........		11.9	12.9	10.7	15.5	18.3	13.4

Table 29. Screen analyses of five samples of Richburg sand from core A, Richburg pool, New York

Size of openings millimeters......................		Depth in feet				
		1366.00	1372.00	1388.00	1399.00	1406.00
Through	On	Percent				
.417	.295	0.0	0.0	0.0	0.1	0.0
.295	.208	0.2	0.9	0.9	2.0	0.8
.208	.147	4.3	6.7	8.4	15.9	12.0
.147	.104	17.6	17.6	21.7	30.2	30.3
.104	.074	35.0	31 4	30.3	24.8	27.5
.074	.061	14.9	14.0	9.8	5.7	7.7
.061	.043	13.6	13.6	10.6	7.0	7.4
.043		14.3	15.8	18.3	14.2	14.3
Average grain diameter—millimeters........		.040	.039	.039	.041	.041
Porosity percent........		15.7	13.9	12.6	15.0	12.6

In Tables 10 to 29, inclusive, the average grain diameter given represents that diameter whose corresponding volume divided into the total volume equals the total number of grains. The following formula was used in its calculation[24]:

$$d_{ave.}=\sqrt[3]{\frac{\Sigma nd^3}{\Sigma n}}$$

In the formula, "d" was taken as the arithmetic mean of the openings in any two consecutive sieves in the Tyler series and "n" as the number of grains of the diameter "d" computed by assuming that the grains were spherical and of an average density of 2.65. The data of Table 30 were prepared for use in computing the average grain diameters.

Table 30. Data for computing average grain diameter

Screen size Tyler series mesh		Size of openings millimeters		Average diameter "d"		Number of grains
Through	Caught on	Through	Caught on	Millimeters	d^3	per gram
10	14	1.651	1.168	1.409	2.80	258
14	20	1.168	.833	1.000	1.00	719
20	28	.833	.589	.711	.359	2,000
28	35	.589	.417	.503	.127	5,680
35	48	.417	.295	.356	.0451	16,000
48	65	.295	.208	.252	.0160	45,000
65	100	.208	1.47	.177	.00555	130,000
100	150	.147	.104	.126	.00200	360,000
150	200	.104	.074	.089	.000705	1,020,000
200	250	.074	.061	.067	.000301	2,390,000
250	325	.061	.043	.052	.000141	5,100,000
325		.043		.022	.0000106	68,000,000

Fancher, Lewis and Barnes give an example of a typical calculation[25]:

In the entire Bradford field, the Bradford Third sand is composed of fine to very fine grains. Over considerable areas the different layers that make up the sand body show remarkable uniformity in grain size, similar to that exhibited by core 11; even in core 19, which shows the greatest range of the cores studied, the variations between the different layers are not large. The materials obtained by crushing an average Bradford Third sand sample and a coarse type of the sandstone to individual grain size are shown in Plate 15.

The grains of the Bradford Third sand are predominantly angular. In a typical sample about 78 percent were classed as angular, 12 percent subangular, 7 percent fairly well rounded, and 3 percent rounded. Part of this angularity is due to secondary silica deposited as a crystalline outgrowth from the original quartz grains after the sand was laid down.

Porosity

The porosity of a sandstone or other reservoir rock represents the percentage of void space in it that is available for occupancy by either liquids or gases. It determines the storage capacity and hence the potential production, provided the pores are well filled with oil or gas. Porosity does not, however, determine the rate of production.

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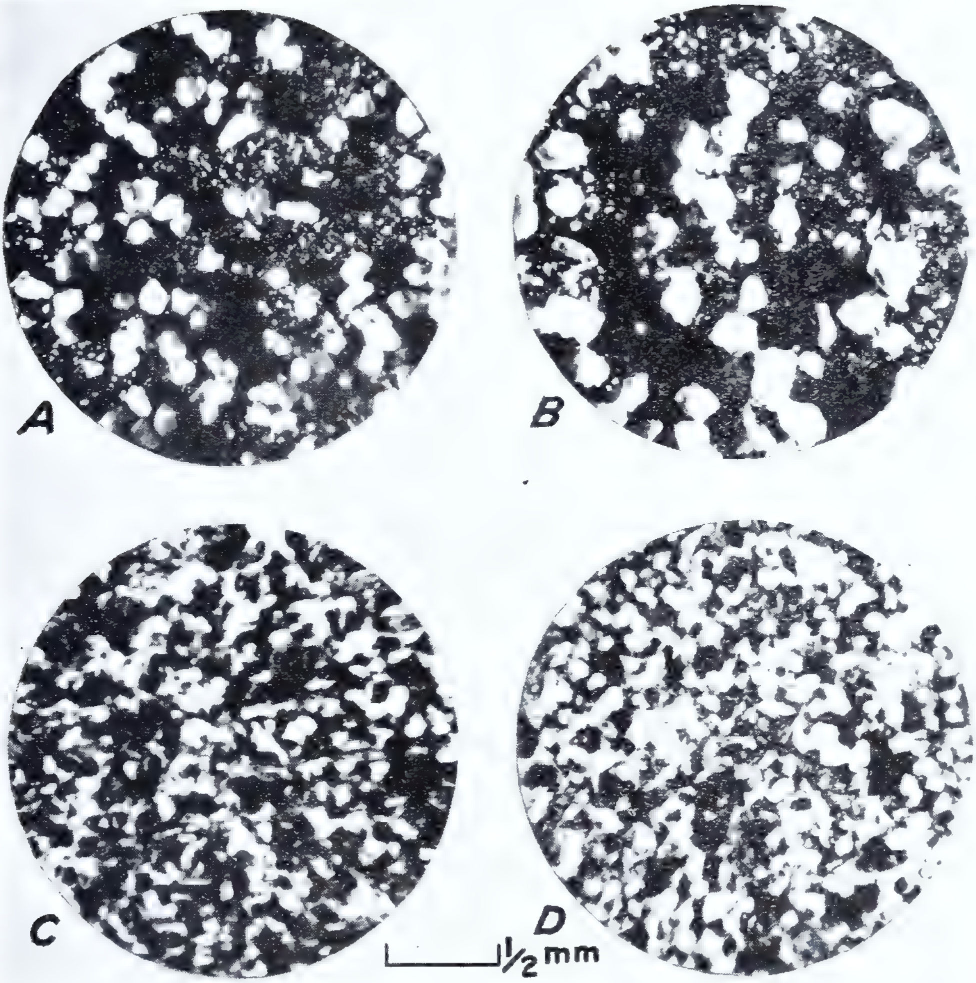
[24] W. M. Weigel, Size and character of grains of non-metallic mineral fillers: U. S. Bur. Mines Tech. Paper 296, p. 21, 1924.

[25] G. H. Fancher, J. H. Lewis and K. B. Barnes, Some physical characteristics of oil sands: Pennsylvania State College Min. Ind. Exper. Station Bull. 12, p. 154, 1933.



A. Grains from sandstone occurring at a depth of 1741.92 feet in core 9; B. Grains from a loosely cemented stratum of Bradford Third sand from a well on the South Branch of Cole Creek; C. Photomicrograph of polished surface of Bradford Third sand cut perpendicular to bedding; D. Same, parallel with bedding.

A distinction should be made between the two types of porosity—total and effective. Total porosity includes all the voids in the sandstone or other rock. Effective porosity, on the other hand, includes only those pore spaces that are connected with one another. Naturally, only those fluids in openings of the latter type are available under present methods of production. The effective porosity is usually less than the total porosity, and can never exceed it. The difference between the effective and total porosities of the Bradford Third sand is usually small, as will be shown later.

All porosities given in this report represent total porosities unless specifically stated otherwise. They were made by the Melcher method[26].

This method is based on the principle that the volume of a fragment of the sand minus the volume of its individual grains equals the volume of the pore space. All measurements are made gravimetrically. It is generally conceded to be the most accurate of the methods thus far proposed for determining total porosities[27].

The procedure followed by the writer with Bradford Third sand was as follows: A representative sample of the sandstone weighing from 20 to 30 grams, free from any fractures, was selected and broken in half. One piece was then extracted for three hours with carbon tetrachloride to remove as far as possible all oil residues, and dried at 105°C. for one hour. The procedure for determining its volume as outlined by Melcher was then followed. The other piece was crushed until all of it passed through a 100-mesh sieve. Oil and moisture were removed by ignition in a silica crucible over a Bunsen burner for five minutes at a relatively low temperature, and five minutes at the maximum attainable with the ordinary burner of this type. It was found that, in the case of Bradford Third sand, extraction with carbon tetrachloride or petroleum ether did not completely remove all petroleum residues, so that it was practically impossible to remove completely all air from the grains in the pycnometer when water was used, and the densities obtained were invariably low when the latter procedure was followed. When kerosene instead of water was used in the pycnometer, however, the densities obtained were very nearly the same as when the oil residues were removed by ignition. The density of the grains was obtained by the pycnometer method as described by Melcher. In Table 31 are shown a comparison of the densities obtained by the two types of procedure and the effects of these differences on the values obtained for the porosities.

31. Comparison of densities of grains of two samples of Bradford Third sand as determined by extraction and ignition methods.

	Sample	Density of grains	Total porosity Percent by volume
Oil and moisture removed by extraction with carbon tetrachloride and drying at 105° C.	1	2.6739	11.0
Kerosene used in pycnometer	2	2.6734	24.0
Oil and moisture removed by ignition	1	2.6706	10.9
Water used in pycnometer	2	2.6689	23.9

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[26] A. F. Melcher, Determination of pore space of oil and gas sands: Trans. Am. Inst. Min. Eng., vol. 65, p. 469, 1921.
Texture of oil sands with relation to the production of oil; Bull. Am. Assoc. Petroleum Geologists, vol. 8, p. 731, 1924.

[27] G. H. Fancher, J. A. Lewis and K. B. Barnes. Op. cit., p. 107.

It will be observed that ignition of the grains of the Bradford Third sand does not change their average density sufficiently to have an appreciable effect on the values obtained for the porosity.

The porosities of the sandstones from the 21 cores of Bradford Third sand already described have been assembled in Table 32. They are also shown graphically by porosity profiles opposite the columnar sections of the cores in figures 8 to 14, inclusive.

Table 32. Total pore space by volume in 21 cores of Bradford Third sand.

Core 1

Depth	Percent
1870.00	19.0
1871.00	17.7
1873.55	10.1
1874.90	10.5
1876.25	16.5
1878.00	10.1
1880.10	10.7
1883.90	11.3
1887.70	12.1
1889.20	15.1
1890.80	14.7
1891.50	3.1
1893.70	11.8
1895.80	15.0
1898.63	10.8
1900.82	12.9
1903.17	16.3
1904.83	10.0
1910.65	12.4
1911.97	16.1

Core 2

Depth	Percent
1424.95	3.8
1426.15	19.4
1426.48	25.2
1426.98	21.1
1428.80	17.3
1428.96	15.7
1431.22	17.9
1432.08	15.2
1434.52	14.7
1434.92	16.1
1435.61	17.0
1436.65	13.6
1437.89	15.1
1439.36	15.4
1439.70	15.9
1440.57	3.7
1441.10	2.0
1442.20	15.2
1443.52	14.9
1445.30	15.7
1445.96	13.8
1446.12	13.6
1446.64	13.3
1447.42	13.8
1448.74	15.8
1449.24	15.2
1450.54	12.3
1452.24	14.6
1453.16	14.2
1454.83	11.3
1457.07	15.6
1458.10	15.6
1460.62	13.3

Core 3

Depth	Percent
1775.28	12.4
1776.60	17.1
1778.45	15.6
1778.75	13.1
1779.37	14.4
1780.10	14.5
1780.75	16.8
1781.90	15.0
1782.70	16.5
1783.20	13.4
1784.00	11.9
1787.45	13.5
1789.05	17.8
1790.75	12.2
1794.60	16.6
1796.75	13.0
1797.30	13.4
1799.70	17.7
1802.60	15.8
1803.75	14.2
1805.40	14.3
1808.70	14.5
1811.25	14.3
1811.45	14.1
1814.90	10.6
1817.50	13.8
1819.70	14.2
1819.90	14.6
1822.00	14.4
1823.45	14.7
1825.15	13.8
1827.50	12.4
1828.60	13.7
1831.10	15.0
1839.45	14.6
1843.50	12.2
1848.85	13.6
1850.70	13.8

Core 4

Depth	Percent
1557.04	15.9
1558.50	15.0
1560.25	12.7
1561.13	16.2
1562.83	16.2
1564.35	16.8
1565.42	13.0
1566.50	16.1
1568.42	13.6
1569.50	15.7
1570.90	15.7
1571.42	15.6
1572.50	13.6
1574.50	11.3
1576.25	5.6
1577.50	16.2
1578.10	14.8
1579.50	14.8
1580.50	14.3
1581.50	14.6
1583.67	14.4
1584.50	12.8
1587.00	15.0
1588.15	16.2
1589.50	12.5
1590.42	17.9
1591.35	18.1
1594.50	15.6
1596.50	13.7
1599.25	11.2
1603.25	14.2
1606.37	15.2
1608.00	14.9
1609.20	13.5
1618.00	14.3

Core 5

Depth	Percent
1080.29	6.0
1081.12	15.9
1082.43	12.2
1084.13	7.1
1085.22	11.6
1086.86	14.4
1089.09	11.9
1091.88	11.0
1094.25	10.4
1095.79	9.4
1097.31	13.6
1098.00	13.8
1100.67	13.5
1101.83	15.5
1104.33	11.1
1106.05	10.2
1111.59	2.8
1114.83	13.9
1121.34	15.9
1123.88	15.1
1125.64	13.8
1128.83	14.5
1131.16	15.1
1134.64	15.7
1138.42	10.3
1142.44	15.4
1146.29	13.8
1147.67	18.4
1148.55	15.3
1152.50	12.6

Core 6

Depth	Percent
1725.33	15.0
1727.18	13.8
1727.91	9.4
1730.50	16.6
1732.95	9.9
1733.80	14.5
1737.00	14.2
1738.50	15.1
1739.70	12.7
1740.80	16.1
1741.73	14.2
1743.65	12.6
1746.06	9.9
1747.25	13.9
1748.75	14.7
1750.70	15.4
1751.50	15.5
1753.00	15.6
1753.45	12.7
1758.65	13.2
1759.80	12.1
1761.80	15.8
1765.60	14.2

Core 7

Depth	Percent
1395.16	12.1
1397.42	15.5
1398.75	12.4
1399.66	15.0
1402.58	15.8
1403.57	12.9
1404.33	12.6
1405.46	12.4
1407.29	14.0
1408.08	15.0
1409.00	14.9
1410.67	15.3
1411.67	15.2
1413.00	15.3
1413.83	13.8
1415.50	13.9
1416.83	14.6
1418.83	11.5
1420.83	13.2
1421.67	11.4
1423.17	11.7
1424.25	11.4
1433.50	15.5
1435.58	16.0
1436.75	10.4
1438.33	12.7
1439.25	14.0
1440.17	15.8

Core 8

Depth	Percent
1567.00	13.5
1568.40	14.6
1568.98	13.9
1569.90	14.3
1571.17	12.4
1571.53	12.8
1572.62	11.8
1573.78	11.0
1574.24	14.1
1575.27	14.2
1576.09	15.6
1576.51	18.2
1577.83	16.4
1578.50	18.6
1579.42	18.1
1580.39	17.5
1581.07	20.7
1582.69	21.7
1583.19	20.2

Core 9

Depth	Percent
1735.29	13.3
1736.71	15.8
1737.25	9.6
1737.58	14.8
1737.92	14.8
1738.71	15.0
1739.08	14.8
1739.42	15.0
1740.08	14.4
1740.50	8.9
1741.92	15.7
1742.58	15.2

Core 9 (Cont.)

Depth	Percent
1743.33	14.8
1744.08	15.5
1745.83	15.9
1746.96	12.4
1747.38	15.7
1749.21	15.2
1750.67	15.1
1751.71	15.0
1751.88	15.5
1752.63	15.4
1753.38	15.6
1755.17	14.8
1756.58	15.7
1759.04	12.5
1759.71	14.8
1761.88	10.1
1762.54	12.4
1763.63	13.3
1766.50	6.5
1770.04	6.0
1771.33	12.1
1774.83	9.7
1777.46	6.5
1779.13	7.3
1782.13	8.2
1783.58	11.2
1784.79	12.9
1786.00	13.7
1786.67	12.6
1787.33	12.8
1787.92	13.9
1788.92	15.3
1792.67	14.6
1795.50	14.2
1796.25	15.2
1799.17	12.9

Core 10

Depth	Percent
1410.33	3.7
1411.50	11.8
1412.50	15.9
1415.33	15.2
1416.00	14.8
1418.00	15.1
1420.58	8.0
1424.00	8.3
1424.42	8.3
1429.42	14.2
1432.08	15.6
1433.75	5.9
1437.42	11.2
1438.33	13.6
1440.33	7.8
1441.75	10.9
1447.08	7.0
1449.50	11.1
1450.83	12.0
1451.42	8.5
1452.67	8.6
1453.58	10.9
1457.00	6.4

Core 11

Depth	Percent
1661.00	13.1
1666.50	15.3
1667.50	12.6
1668.50	13.6
1668.91	12.1
1669.58	14.3
1669.92	15.5
1670.00	15.8
1671.00	15.0
1672.08	14.8
1673.41	12.1
1679.04	15.8
1679.36	13.9
1680.02	12.3
1683.12	11.7
1687.02	8.1

Core 11 (Cont.)

Depth	Percent
1687.99	12.8
1688.57	11.9
1689.55	14.3
1690.80	15.2
1691.07	14.5
1692.40	12.8
1693.73	13.3
1694.00	13.5
1695.00	13.8
1695.80	14.1
1696.60	13.3
1697.39	14.7
1698.52	13.5
1700.27	14.3
1701.43	15.3
1701.83	14.7
1703.97	8.0

Core 12

Depth	Percent
1557.16	11.9
1559.71	16.5
1560.66	15.0
1561.90	16.4
1562.40	16.0
1563.56	15.5
1565.31	17.5
1565.65	17.7
1566.50	17.2
1568.17	17.0
1569.50	20.9
1571.30	22.6
1572.88	20.5
1574.21	14.2
1574.98	15.8
1576.27	19.3
1578.27	24.3
1580.27	13.1
1582.04	14.3
1582.60	15.0
1583.44	12.9
1584.44	19.0
1585.53	19.6
1586.94	18.0
1588.94	20.9
1591.94	15.1
1593.07	14.5
1593.44	14.9
1593.80	14.3
1594.16	7.2
1595.40	14.1
1595.88	8.7
1596.73	8.2
1602.10	13.3
1607.51	9.0

Core 13*

Depth	Percent
1240.40	17.3
1242.00	16.5
1245.30	14.0
1246.20	16.5
1247.70	14.2
1248.70	15.1
1254.70	15.1
1255.30	15.6
1258.80	15.5
1260.40	16.3
1264.00	16.4
1264.40	15.5
1267.80	15.6
1269.70	11.5
1270.30	14.0
1273.80	14.1

(*Porosities for Core 13 determined by A. F. Melcher, all others by Chas. R. Fettke.)

Core 13 (Cont.)

Depth	Percent
1275.00	5.6
1279.00	15.1
1281.00	16.2
1282.30	13.0
1292.30	9.3

Core 14

Depth	Percent
1744.58	15.1
1745.57	15.4
1746.38	14.7
1747.01	15.3
1747.33	14.2
1748.01	17.2
1749.17	15.1
1749.93	13.9
1750.30	13.8
1750.67	11.2
1752.02	12.7
1752.51	16.8
1752.93	17.1
1753.34	15.4
1754.01	15.6
1755.01	11.9
1755.34	12.1

Core 15

Depth	Percent
1413.05	12.5
1414.60	16.3
1415.20	16.9
1418.80	15.9

Core 16

Depth	Percent
1675.98	14.6
1676.48	17.9
1676.81	21.8
1677.98	22.7
1678.50	21.6
1678.92	20.8
1679.75	21.8
1682.96	16.8
1684.00	19.5
1684.58	20.2
1685.38	19.3
1686.08	17.9
1686.63	16.3
1687.17	13.5
1687.83	15.9
1688.46	16.4
1688.79	16.6
1689.17	14.0
1690.00	21.6
1691.00	9.9
1692.00	17.7
1692.88	14.5
1694.19	14.7
1696.00	14.8
1697.50	14.9
1698.52	14.5
1699.13	15.1
1700.00	10.8
1701.10	10.4
1705.53	10.5

Core 17

Depth	Percent
1959.65	6.3
1960.20	17.4
1960.50	15.7
1963.30	17.5
1963.80	17.4
1964.35	17.2
1965.23	6.5
1966.30	7.6
1967.80	14.8
1968.83	14.1
1969.88	8.4
1971.23	11.6
1971.65	13.3

Core 17 (Cont.)

Depth	Percent
1972.35	15.1
1973.30	15.0
1973.65	15.7
1974.50	15.8
1975.82	16.0
1977.18	10.9
1977.75	14.2
1978.05	13.3
1979.35	14.9
1979.85	13.7
1980.25	15.0
1981.24	11.0
1987.92	14.7
1989.12	13.8

Core 18

Depth	Percent
2039.10	14.3
2040.80	14.2
2044.15	5.7
2044.53	13.8
2046.15	14.7
2047.77	14.1
2049.00	14.8
2049.80	14.1
2050.91	13.0
2051.75	14.0
2053.00	13.1
2054.23	9.7
2055.20	16.3
2056.08	21.5
2056.55	14.1
2058.03	24.1
2059.34	26.0
2061.00	24.7
2061.70	25.6
2063.00	24.1
2064.40	21.1
2064.80	18.8
2065.97	18.9
2066.80	15.4
2067.55	15.8
2068.47	18.9
2069.45	14.7
2069.50	15.6
2070.57	9.6
2071.00	14.1
2072.16	16.6
2073.60	13.9
2074.60	12.0
2075.88	13.9
2077.10	16.5
2078.66	15.4
2081.33	15.3
2084.43	14.6
2086.23	11.6
2086.50	15.2
2086.93	13.9
2087.95	8.1
2089.23	14.5
2089.88	14.4
2092.90	10.4

Core 19

Depth	Percent
2029.27	11.7
2032.11	10.8
2032.36	13.0
2036.25	11.4
2036.50	12.2
2038.05	11.4
2040.59	13.4
2041.89	14.1
2044.58	13.9
2044.83	13.8
2045.33	13.9
2045.55	13.3
2047.13	23.3
2047.33	23.6
2050.63	24.3
2051.07	21.7

Core 19 (Cont.)	
Depth	Percent
2051.32	23.9
2052.47	22.4
2053.07	22.7
2054.57	16.8
2055.32	13.3
2056.07	15.3
2056.32	15.3
2058.07	15.1
2060.82	14.6
2063.56	16.2
2064.25	17.8
2065.05	2.5
2065.68	13.1
2067.04	15.5
2067.29	16.5
2068.54	15.2
2069.39	13.4
2071.69	13.9
2073.93	12.1
2077.88	9.9

Core 20	
Depth	Percent
1888.33	13.5
1889.25	14.1
1889.83	14.1
1891.50	14.7
1892.50	14.2
1893.00	13.0
1894.50	13.0
1895.67	13.1
1899.75	13.0
1901.04	12.4
1902.50	12.7
1903.50	13.6
1904.00	13.9
1904.50	13.5
1905.00	14.0
1906.00	15.7
1907.00	14.0
1908.00	15.4
1908.83	15.7
1909.83	12.4

Core 20 (Cont.)	
Depth	Percent
1911.74	11.8
1914.58	11.3
1916.92	14.0
1918.25	15.2
1931.66	14.9
1932.33	15.1
1933.25	14.0
1933.67	13.6
1936.00	5.7

Core 21	
Depth	Percent
1908.00	13.2
1909.09	11.9
1909.84	10.7
1912.04	12.9
1913.49	13.6
1917.77	13.2
1919.07	13.4
1925.14	11.2

Core 21 (Cont.)	
Depth	Percent
1925.83	12.7
1928.29	10.8
1929.96	10.7
1934.08	15.4
1934.28	13.7
1934.70	15.5
1935.33	17.8
1936.03	18.3
1937.73	10.4
1939.38	11.4
1940.31	13.3
1941.30	13.6
1943.93	13.4
1945.83	11.3
1949.28	14.5
1950.33	13.6
1951.38	11.0

The thickness of oil-bearing sand with a porosity of 10 percent or more in each core and its average porosity and, where the sand body can be divided into several distinct parts, similar data for each part are summarized in Table 33.

Table 33. Average porosities of Bradford Third sand from 21 cores.

Core		Thickness of oil-bearing sand in feet		Average per cent porosity	
1.	Entire sand body	23.00		13.4	
	Gas "pay"		7.50		14.4
	Oil "pay"		15.50		12.9
2.	Entire sand body	33.44		15.0	
	Gas "pay"		13.27		16.7
	Oil "pay"		20.17		13.9
3.	Entire sand body	40.40		14.5	
	Gas "pay"		6.30		15.6
	Oil "pay"		34.10		14.3
4.	Entire sand body	40.01		14.8	
5.	Entire sand body	44.46		13.9	
	Top "pay"		16.18		13.9
	Shale parting		5.26		12.2
	Bottom "pay"		23.02		14.0
6.	Entire sand body	28.04		14.6	
7.	Entire sand body	34.98		13.9	
8.	Entire sand body	15.16		15.9	
9.	Entire sand body	36.49		14.1	
	Top "pay"		24.57		14.4
	Shale parting		.71		12.1
	Bottom "pay"		11.21		13.7
10.	Entire sand body	16.01		13.8	
11.	Entire sand body	27.59		14.1	
	Top "pay"		11.08		14.2
	Shale parting		2.00		11.7
	Bottom "pay"		14.51		14.4
12.	Entire sand body	40.17		17.0	
	Gas "pay"		10.19		16.4
	Oil "pay"		29.98		17.2
13.	Entire sand body	38.14		14.8	
14.	Entire sand body	8.00		14.9	
15.	Entire sand body	5.30		15.5	
16.	Entire sand body	28.19		16.4	
17.	Entire sand body	21.27		14.8	
18.	Entire sand body	41.79		16.4	
	Upper portion		13.64		14.1
	Middle portion "loose streak"		9.97		22.8
	Lower portion		18.18		14.7
19.	Entire sand body	43.81		15.0	
	Upper portion		18.26		12.7
	Middle portion "loose streak"		7.44		23.3
	Lower portion		18.11		14.9
20.	Entire sand body	23.52		13.8	
21.	Entire sand body	28.50		12.8	

The per cent of total porosity has the following relation to the density of the bulk sample and the density of the grains.

$$\text{Total porosity} = 100 \left\{ 1 - \frac{\text{Density of bulk sample}}{\text{Density of grains}} \right\}$$

If the average density of the grains composing the Bradford Third sand were constant over the entire field, which it is not, it would simply be necessary to determine the grain density once and thereafter the porosities could be calculated from the bulk density. In order to determine how much of an error might result in estimating porosities in this manner, 110 porosities have been plotted against the corresponding bulk densities in Figure 24. They represent data obtained in connection with the analysis of three cores of the Bradford Third sand—one taken in the northeastern part of the field, one in the central, and one in the southern. The average grain density, based upon the 110 determinations, which ranged from 2.6475 to 2.7053, was found

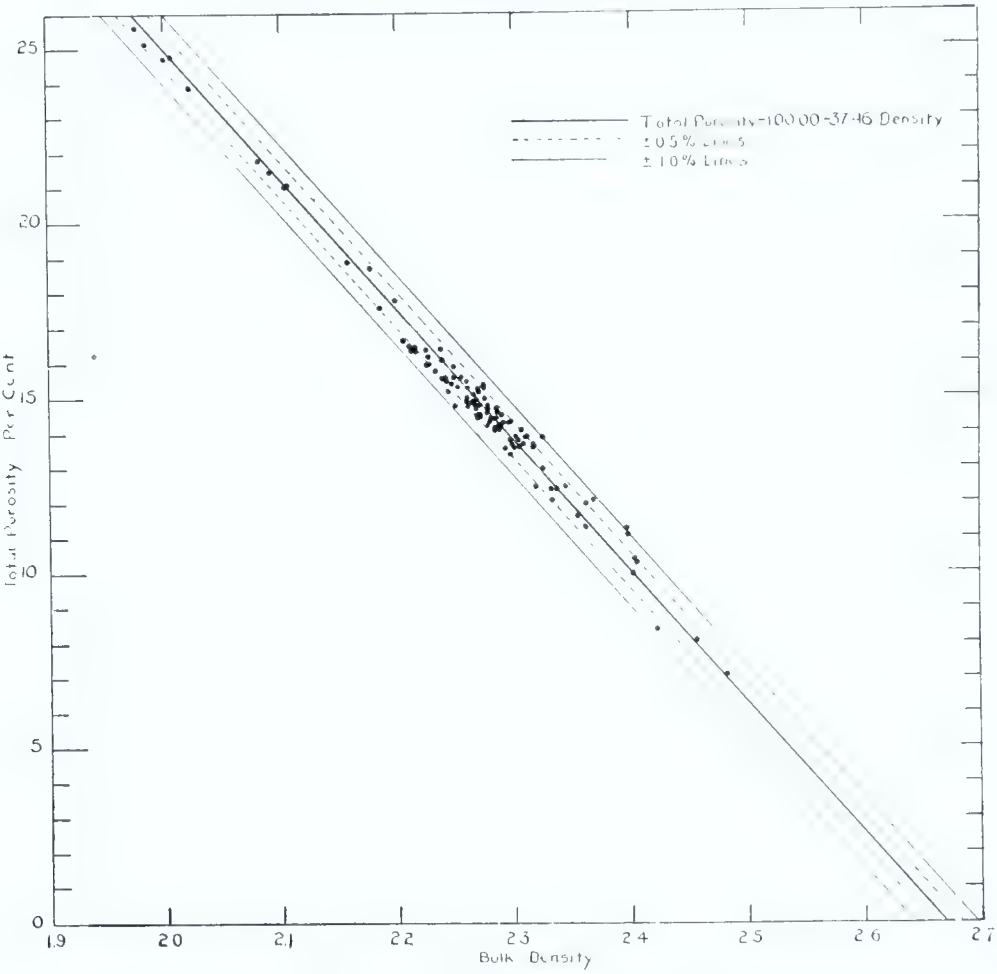

FIGURE 24. **Relation of porosity to bulk density in Bradford Third sand.**

to be 2.6692. Substituting this value for the density of the grains, the above equation becomes:

$$\text{Total porosity} = 100 - 37.464 \text{ bulk density}$$

An inspection of Figure 24 shows that only 15 out of the 110 samples deviated more than ±0.5 percent from the result obtained by using this formula and only one more than ±1.0 percent.

In order to obtain an idea of the magnitude of the difference between the total and the effective porosities of typical samples of Bradford Third sand, the effective porosities of 20 samples from core 18 were determined by the Barnes method[28]. The results are shown in Table 34.

Table 34. Total and effective porosities of 20 samples of Bradford Third sand from core 18.

Depth feet	Total porosity by Melcher method	Effective porosity by Barnes method	Difference
2039.10	14.3	13.6	0.7
2046.15	14.7	14.6	0.1
2049.00	14.8	14.7	0.1
2049.80	14.1	13.0	1.1
2050.91	13.0	12.9	0.1
2054.23	9.7	9.7	0.0
2059.34	26.0	25.9	0.1
2061.70	25.6	25.3	0.3
2063.00	24.1	24.0	0.1
2064.80	18.8	18.0	0.8
2067.55	15.8	15.7	0.1
2068.47	18.9	18.5	0.4
2069.45	14.7	14.7	0.0
2072.16	16.6	16.3	0.3
2073.60	13.9	13.0	0.9
2077.10	16.5	16.1	0.4
2078.66	15.4	14.8	0.6
2081.33	15.3	14.8	0.5
2086.50	15.2	15.2	0.0
2089.88	14.4	14.3	0.1

An inspection of Table 34 shows that in most samples of Bradford Third sand there is comparatively little difference between the total and effective porosity. In some of the samples the differences either came within the limits of experimental error or the two were practically the same.

A comparison of porosity with grain size indicates that the percentage of fine material, that is, grains that pass through a 325-mesh sieve, is one of the determining factors in the porosity of the sand. The lower this percentage, the higher the porosity, since the fine particles fill the voids between the larger particles and thus reduce porosity. In general, in the Bradford Third sand, the layers with high porosities (more than 20 percent) consist of coarser grains than the others. The higher porosity is apparently owing to the fact that these layers were sorted better during deposition and less silt was deposited in them.

Microscopic examination has revealed that the low porosities of certain sandstone layers may be due to three causes: (1) large amounts of interstitial clay minerals; (2) greater percentages of silica deposited as secondary crystalline outgrowth from the original quartz grains and as crypto-crystalline silica; and (3) large amounts of calcite or related carbonates between the quartz grains.

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[28] K. B. Barnes, A method for determining the effective porosity of a reservoir-rock; Pennsylvania State College Min. Ind. Exper. Station Bull. 10, 1931.

Permeability

The permeability of an oil or gas sand is its capacity for transmitting fluids, either liquids or gases, under pressure. This property of the sand is of particular importance in connection with increasing the recovery of petroleum by water flooding or repressuring with air or gas, inasmuch as on it, to a considerable extent, depends whether rejuvenation methods are economically feasible in a particular pool, what pressures are necessary, and what is the best well spacing to use.

The permeability of a sand depends on the size and shape of the openings and the extent to which these communicate with one another, as well as the ratio of their volume to the total volume of the sand.

Actual grain size, degree of uniformity of grain size, shape of grains, manner of packing of grains, and amount of cementing material between the grains are all factors that determine the relative permeabilities of different layers of the sand. All, with the exception of the first, have an important bearing on the porosity and are, to a considerable extent, reflected in it. Hence actual grain size and porosity are usually excellent criteria for judging the relative permeabilities of different layers of sand. Permeability and porosity, however, are not synonymous terms and should not be used interchangeably. Porosity simply indicates the percentage of void space present in the sand that is available for occupancy by either liquids or gases. It does not give a picture of the pore pattern, namely, the size of the openings, their shape, and the extent to which they are connected, all of which influence the permeability.

Possible cross-bedding, lensing, and variations in grain size and porosity parallel with, as well as perpendicular to, the bedding in different layers of the sand must not be overlooked when considering the permeability of the sand body in place.

Another condition that affects the ease with which water or any other driving medium can be forced through different layers of the sand depends on whether the entire pore space is filled either with liquid or with gas, or whether liquid and gas are both present and, if so, their relative proportions. The viscosity of the oil is another factor. The relative permeability of a certain layer of sand as determined in the laboratory, therefore, may not necessarily be a true criterion of the way in which that particular layer will behave under the conditions in the sand body.

The permeability of a porous medium to fluids can be defined as the rate of flow of a specified fluid through a unit cross-section of the porous medium under a unit pressure gradient and conditions of viscous flow. Wyckoff, Botset, Muskat, and Reed have proposed to call the unit of permeability the "**darcy**" after D'Arcy who first formulated the law of porous flow[29].

The permeability in terms of darcys expresses the rate of flow in milliliters per second of a fluid of one centipoise viscosity through a cross-section of one square centimeter of the porous medium, under a pressure gradient of one atmosphere (76.0 cm Hg.) per centimeter and conditions of viscous flow. In sands of low permeability, such as the Bradford Third, it is convenient to use, as a sub-unit, the millidarcy which is equivalent to 0.001 darcy.

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[29] R. D. Wyckoff, H. G. Botset, M. Muskat, D. W. Reed, Measurement of permeability of porous media: Bull. Am. Assoc. Petroleum Geologists, vol. 18, p. 167, 1934.

Wyckoff, Botset, Muskat, and Reed in their paper and also Fancher, Lewis and Barnes[30] have described in considerable detail the methods for measuring the permeability of oil and gas sands. The procedure followed by the writer has been essentially that outlined by these men.

Cubes, one-half inch on a side, were used in the case of the Bradford Third sand. This size was adopted because many of the biscuits obtained with a cable-tool core-barrel are only thick enough to yield test pieces of this dimension. The cubes were first cut out slightly oversize with a Norton "Crystolon" bakelite-bonded disc and then carefully ground to exact size on a coarse carborundum wheel. For removing the cuttings and keeping the surface clean, a jet of compressed air was used. The test piece was held with the fingers and care was exercised at all times to avoid any undue heating.

After the cubes had been ground to exact size, they were extracted for three hours or more with carbon tetrachloride to remove, as far as possible, all traces of oil content and dried at 105° C. for one hour. They were then inserted in a square hole cut in a No. 7 hard rubber stopper which fitted into a brass holder (figure 25). The holder was connected into the flow line by means of a brass union at each end. The method of mounting used, which was originally suggested by W. A. Copeland, does not destroy the sample. With the cubes it permits measurements to be made in three directions, two parallel to the bedding and one at right angles to it. In all tests, the direction of flow through the sample was reversed for a check by turning the cube around. This made possible six sets of measurements on the same sample. The rubber stopper was tested for leakage at frequent intervals by inserting a brass cube of the same dimension as the test piece and using pressure up to 75 pounds. It was found that the stoppers served well and long without leaking.

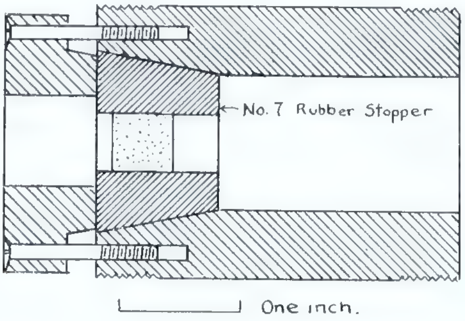

FIGURE 25. **Cross-section of sample holder for permeability tests.**

Air under conditions of viscous flow was used as the test fluid. It was dried by passing through calcium chloride in a container inserted between the stabilizing tank and the sample holder. Pressures were measured by a mercury manometer at the input end and a water manometer at the output end. Only in a few cases, where pressure differential of more than one atmosphere was required on account of the low permeability of the sample,

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[30] G. H. Fancher, J. A. Lewis and K. B. Barnes, Some physical characteristics of oil sands: Pennsylvania State College Min. Ind. Exper. Station Bull. 12, pp. 122-141, 1933.

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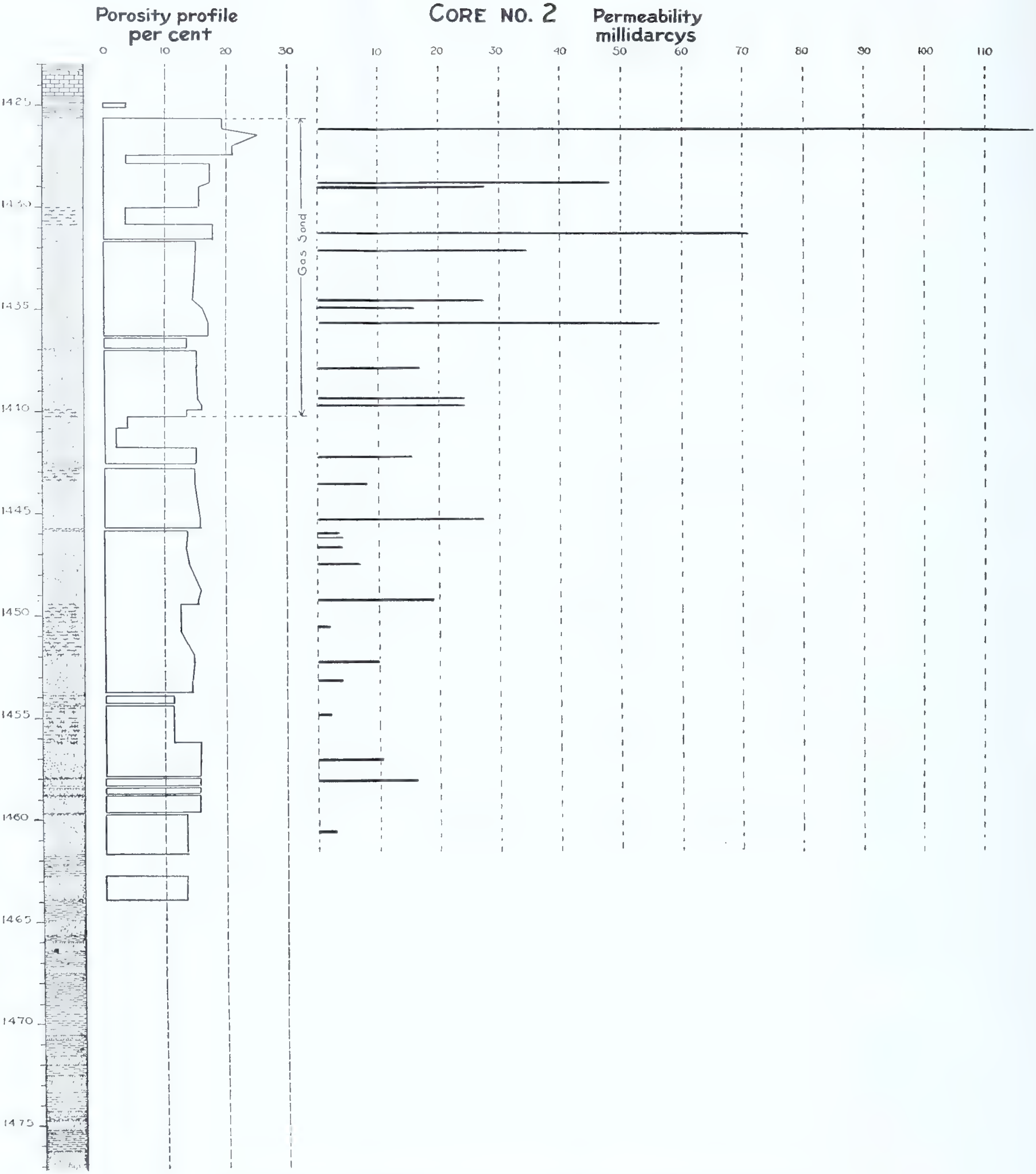
PLATE 16



Section and porosity and permeability profiles of core 2.

was a test gauge used. A standard mercury barometer was available for obtaining atmospheric pressure. The volume of air passing through the sample was measured with a Sargent wet test gas meter whose calibration had been checked. A stopwatch was used for timing.

The equation of Wyckoff, Botset, Muskat and Reed was used for calculating the permeability. When air is used as the test fluid, this is as follows:

$$k = \frac{\mu \overline{Q} L}{A (P_1 - P_2)} \times 1000$$

Where k = permeability in millidarcys.

$\overline{Q}$ = milliliters of air passing through sample per second reduced to mean pressure $\overline{P}$.

$$\overline{P} = \frac{P_1 + P_2}{2}$$

P_1 = absolute input pressure (gauge plus atmospheric) in atmospheres.

P_2 = absolute output pressure in atmospheres.

L = length of sample in centimeters.

A = area of cross-section of sample in square centimeters.

μ = viscosity of air in centipoises at temperature of test.

A chart showing the viscosity of air versus temperature was prepared from the following data:[31]

Temperature °C.	Viscosity in centipoises
10	0.01759
20	0.01808
30	0.01856

Detailed permeability studies were made of cores 2, 11 and 18. The data obtained have been assembled in Tables 35, 36 and 37, and are shown graphically in Plates 16, 17 and 18.

35. Permeability and total porosity of 28 samples from core 2.

Depth feet	Permeability Millidarcys	Total porosity per cent by volume	Depth feet	Permeability Millidarcys	Total porosity per cent by volume
1426.15	119.41	19.4	1443.52	8.22	14.9
1428.80	47.99	17.3	1445.30	27.51	15.7
1428.96	27.65	15.7	1445.96	3.47	13.8
1431.22	70.76	17.9	1446.12	4.02	13.6
1432.08	34.46	15.2	1446.64	4.02	13.3
1434.52	27.41	14.7	1447.42	7.07	13.8
1434.92	16.18	16.1	1449.24	9.12	15.2
1435.61	56.22	17.0	1450.54	2.84	12.3
1437.89	16.99	15.1	1452.24	10.33	14.6
1439.36	24.36	15.4	1453.16	4.17	14.2
1439.70	24.50	15.9	1454.83	2.17	11.3
1440.57	0.00	3.7	1457.07	10.92	15.6
1441.10	0.00	2.0	1458.10	16.51	15.6
1442.20	15.63	15.2	1460.62	2.78	13.3

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[31] International Critical Tables, Vol. 5, p. 2, 1929.

Table 36. Permeability and total porosity of 28 samples from core 11.

Depth feet	Permeability Millidarcys	Total porosity per cent by volume	Depth feet	Permeability Millidarcys	Total porosity per cent by volume
1661.00	2.15	13.1	1689.55	5.50	14.3
1667.50	.32	12.6	1690.80	8.91	15.2
1668.50	.83	13.6	1692.40	1.81	12.8
1668.91	.47	12.1	1693.73	.99	13.3
1669.58	5.00	14.3	1694.00	.38	13.5
1670.00	9.09	15.8	1695.00	1.89	13.8
1671.00	3.83	15.0	1695.80	3.38	14.1
1672.08	2.85	14.8	1696.60	2.19	13.3
1673.41	.19	12.1	1697.39	5.44	14.7
1679.04	6.37	15.8	1698.52	3.12	13.5
1680.02	.07	12.3	1700.27	5.34	14.3
1683.12	.23	11.7	1701.43	8.32	15.3
1687.99	2.83	12.8	1701.83	3.25	14.7
1688.57	2.19	11.9	1703.97	.10	8.0

Table 37. Permeability and total porosity of 39 samples from core 18.

Depth feet	Permeability Millidarcys	Total porosity per cent by volume	Depth feet	Permeability Millidarcys	Total porosity per cent by volume
2039.10	6.15	14.3	2066.80	8.82	15.4
2040.80	4.87	14.2	2067.55	10.71	15.8
2044.15	.16	5.7	2068.47	33.24	18.9
2044.53	2.10	13.8	2069.45	6.04	14.7
2046.15	8.89	14.7	2069.50	14.94	15.6
2047.77	5.65	14.1	2070.57	.55	9.6
2049.00	4.63	14.8	2071.00	4.73	14.1
2049.80	5.60	14.1	2072.16	17.13	16.6
2050.91	1.80	13.0	2073.60	3.28	13.9
2051.75	2.88	14.0	2074.60	.74	12.0
2053.00	1.67	13.1	2075.88	1.84	13.9
2054.23	.07	9.7	2077.10	11.32	16.5
2055.20	26.91	16.3	2078.66	7.42	15.4
2056.55	3.92	14.1	2081.33	4.96	15.3
2058.03	117.35	24.1	2086.50	8.68	15.2
2059.34	356.24	26.0	2086.93	3.37	13.9
2061.00	208.12	24.7	2087.95	.18	8.1
2061.70	224.04	25.6	2089.23	6.82	14.5
2064.80	12.87	18.8	2089.88	4.71	14.4
2065.97	10.78	18.9			

The three cores studied show the three types of conditions that are most frequently encountered in the Bradford field. Core 11 was taken in a part of the field where excellent results have been obtained by water-flooding. The permeabilities are relatively low, 9.09 millidarcys being the maximum observed. The outstanding feature, however, is the fact that the permeabilities of each one of the important layers of sandstone comprising the sand body show about the same range of permeability.

Over much of the dome in the northeastern part of the field, the upper 35 - 40 feet of the Bradford Third sand originally contained considerable volumes of gas and little or no oil. The sand body in much of this area is 90 feet thick. Another similar gas area occurs on the structural nose southwest of Rixford. Here the upper 20-25 feet of sand was gas-bearing, the total thickness ranging from 45 to 70 feet. Core 2 came from the northeastern edge of the first area. Although the gas "pay" in this core contained some oil, the degree of saturation was considerably less than that of the underlying oil "pay." The outstanding feature is the high permeability of the gas "pay" as compared with that of the oil "pay." If this portion of the sand body is not properly packed off much trouble from by-passing is experienced in water-flooding operations.

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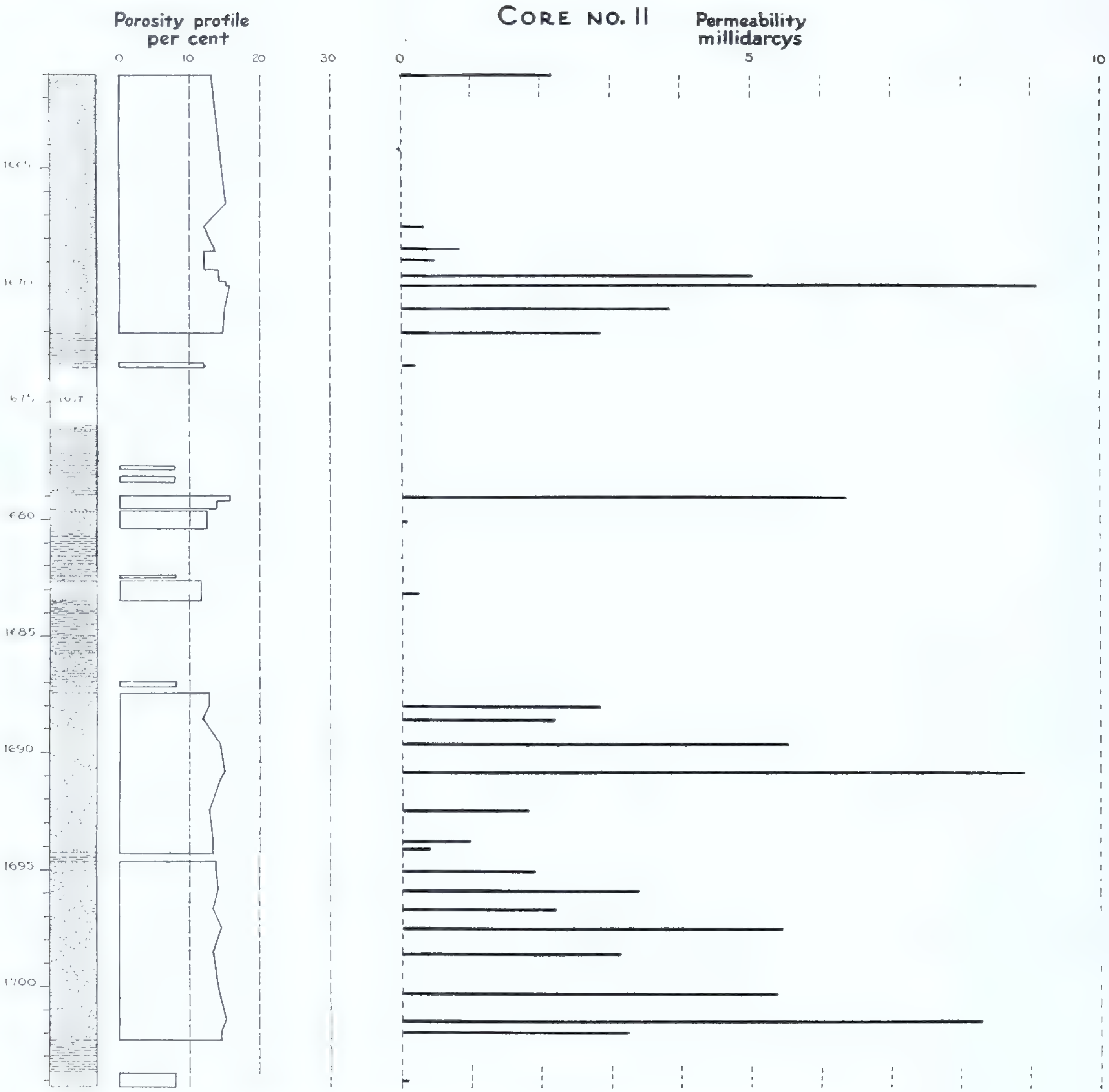
PLATE 17



Section and porosity and permeability profiles of core 11.

In certain parts of the Bradford field, particularly in the eastern lobe, but not restricted entirely to it, there are certain layers in the sand body called "loose streaks," which possess a much higher degree of permeability than the average Bradford Third sand. The layers are also characterized by a slightly coarser texture and possess a higher porosity. Core 18 shows such a "loose streak." The "loose streaks" present one of the most difficult conditions to contend with in the application of the water drive in the Bradford field. In Core 18, the very permeable layer occurs near the middle of the sand body. They are not necessarily confined to this position, however. In some places they occur in the upper and at others in the lower part.

Permeabilities were measured in many samples in two directions, both parallel with the bedding but at right angles to each other. The direction of flow was reversed in each case. The results obtained for any one sample along these two directions, as a rule, showed only slight, if any, differences. Permeabilities measured perpendicular to the bedding, however, in most cases, were found to be appreciably lower than those measured parallel with it, the amount ranging anywhere from 20 to 35 percent, or even more. In relatively few samples was the permeability found to be greater perpendicular to than parallel with the bedding. The values for the permeabilities given in the tables are all based upon measurements parallel with the bedding.

Some idea of the nature of the pores in the Bradford Third sand can be obtained from the photomicrographs shown in Plate 15, C, D, representing polished surfaces by reflected light. The sample was first hardened with bakelite varnish to prevent, as much as possible, the tearing out of any of the grains, and then polished in the usual manner. The light areas show the mineral grains and the black ones represent the pores. C is a surface perpendicular to the bedding and D parallel with it, of a sample taken at a depth of 1741.92 feet in core 9. The bedding is clearly shown in the former by the alignment of the grains. The sample had a porosity of 15.7 percent.

Inasmuch as porosity is one of the factors entering into permeability, the permeabilities obtained in the study of the three cores have been plotted against porosities in Figure 26, using log-log coordinates. Two determinations on highly permeable fragments of Bradford Third sand recovered after a shot from a well southeast of Rixford, have been included. The median line shown represents the line of best fit obtained by the method of least squares through minimizing the squares of the vertical deviations of the points from this line. In terms of millidarcys, this line gives the following relation between permeability and porosity:

$$k = 5.1 \times 10^{-8} p^{6.9}$$

The graph shows that porosity is one of the important factors in determining permeability of the Bradford Third sand. It also shows, however, that it is not the only factor. In general, one would expect the sands with the coarser grains to possess permeabilities greater than those indicated by the median line and those with the finer grains, lower. Attention has been called to the fact that, as a general rule, those layers of the Bradford Third sand having the highest porosities are somewhat coarser in texture than the average. On the other hand, layers of relatively low porosity frequently are somewhat finer in texture than the average and their permeabilities are, therefore, lower than would be expected from the position of this line. An average Bradford Third sand sample with a porosity of 14.5 percent should possess a permeability of about 5 millidarcys, according to the graph. (Figure 26.)

Lateral and Vertical Variations

In the discussion of the well records from McKean County and adjacent areas, it has been shown that the Bradford Third sand was deposited over a very much larger area than that occupied by the Bradford oil pool. It is in the latter area, however, that the sand is thickest and most continuous. But even in this area, as has already been brought out, wide variations exist in total thickness and number and thickness of shale partings.

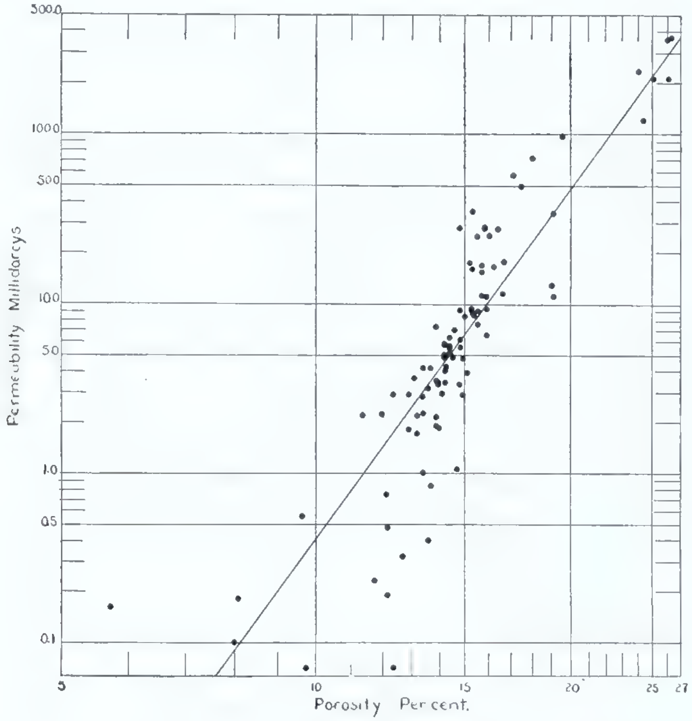


FIGURE 26. **Relation of permeability to porosity in the Bradford Third sand.**

Some of the greatest thicknesses of sandstone have been found in the northeastern part of the Bradford pool in the area occupied by the Knapp Creek dome, shown on Plate E. In Well W-5, near the head of Indian Creek, the sand body is 118 feet thick, of which 99 feet are sandstone. Unfortunately, from the standpoint of oil production, the pores of the upper half of the sandstone were originally filled largely with gas and contain little or no oil. Over much of this area the sand body has a total thickness of 90 feet, but the upper 35 to 40 feet originally contained considerable volumes of gas and little or no oil.

Cores 1, 2 and 3 are typical of conditions in the marginal portions of the dome area. The upper or gas-bearing portion of the sandstone is characterized by somewhat coarser grains than the average Bradford Third sand. Slightly coarser layers occur in the underlying oil "pay" also. The upper part of the sand body in most places has a much higher permeability than th 5 to

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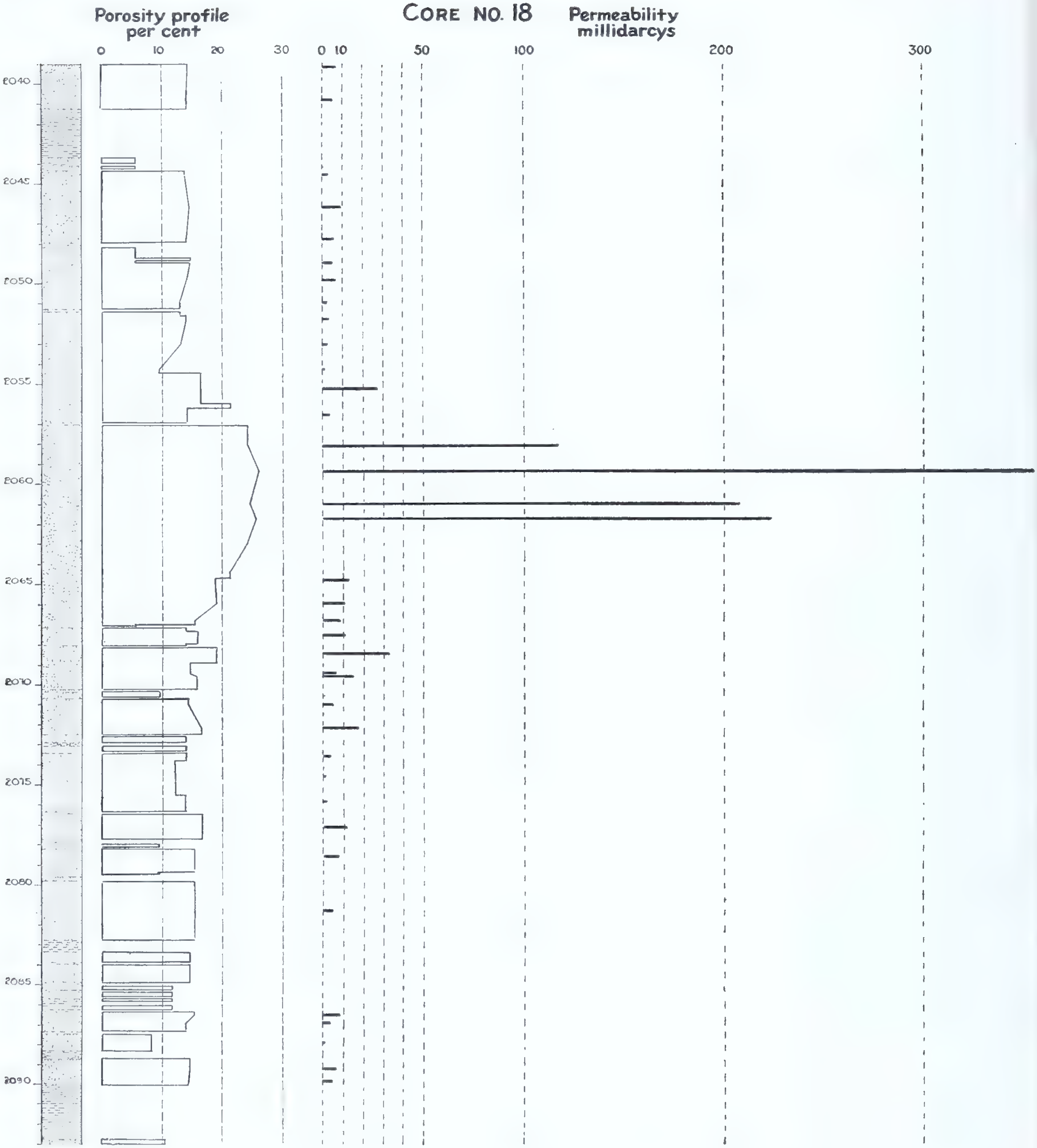

Section and porosity and permeability profiles of core 18.

the lower, being of the magnitude of 120 millidarcys as compared with 5 to 15 millidarcys for normal Bradford Third sand.

To the north, northeast and southeast of the dome the sand body thins, the amount of actual sandstone present becomes less and less and the shale partings increase in number and thickness until, at the margins of the field, comparatively little sandstone remains.

To the southwest the sand body has a good development over an area five to eight miles wide, for about six miles. This includes the north-central part of the Bradford oil pool. The amount of actual sandstone usually ranges anywhere from 25 to 65 feet. Commonly, it is split into a number of distinct layers by shale partings. Cores 4, 6, 7, 9 and 11 are typical of this area. The individual layers of sandstone show remarkable uniformity of grain size, porosity and permeability.

West and southwest of Rixford another gas-bearing zone, similar to the one on the Knapps Creek dome, was found in the upper part of the sand body on a low dome along a structural nose. Here the upper 20 to 25 feet of sand were gas-bearing, the total thickness ranging from 45 to 70 feet. Core 12 was obtained in this area near its western margin. It is characterized by a greater thickness of sandstone than normal and is also freer from shale partings. Some of the sandstone layers are coarser than average and their porosities are appreciably higher.

In the vicinity of Corwins Corners the belt of thick sand development splits into two lobes. Along the northwestern lobe the thick sand continues in a southwesterly direction nearly eight miles over a width of about three miles. In total thickness, and number and thickness of shale partings, it does not differ materially from the north-central part. Cores 5 and 13 are typical of the northwestern lobe.

The southeastern lobe also trends in a southwesterly direction. It shows considerably more irregularity than the northwestern lobe, however. The thickest sand occurs in a belt about one mile wide along its northwestern flank for about nine miles and another belt, also approximately one mile wide and about eight miles long, along its southeastern flank. An intervening belt, about one mile wide, of thinner sand separates the two.

Over portions of the southeastern lobe the characteristics of the sand body are very similar to those in the north-central area and the northwestern lobe, as shown by core 17. At several localities, however, there are elongate bodies of relatively thick sandstone containing few, or almost no shale partings, on the sides of which the sand thins rapidly and has numerous shale layers interfingering with it. Some of the larger elongate bodies are 8,000 feet or more in length and only 1,200 to 1,500 feet wide. Core 19 came from such an area. Most of them are smaller and the ratio of their lengths to their widths is greater. In many places, the trends of the longer axes of these sand bodies are roughly parallel to the long axis of the lobe. Part of the sandstone in them is somewhat coarser than that on either side. Porosities in excess of 20 percent, as compared to 14 to 16 percent for normal Bradford Third sand, are common. These coarser parts have high permeabilities, in some places up to 350 millidarcys. Elongate bodies of sandstone of this type are not confined to the southeastern lobe, but they are more common along it than in other parts of the field.

A belt from 2½ to 3 miles wide, in which the Bradford Third sand is very thin, or practically absent, separates the northwestern and southeastern lobes. Core 15 illustrates the conditions in this area.

Toward and along the margins of the Bradford pool the shale layers interbedded with the sandstone increase in thickness and the sandstone layers become thinner and fewer. Core 10 illustrates this condition. Away from the pool, only one or two comparatively thin lenses of sand are usually present at the Bradford Third horizon and, in some places, the development of sand is so insignificant that its presence is not recognized by the drillers, and other sandstones above or below it are sometimes mistaken for it. The thinning in most places is more gradual on the northwest side than on the southeast. To the northwest, however, typical chocolate-colored Bradford Third sand disappears from this horizon a short distance beyond the limits of the pool, but to the southeast and east it can be traced at least as far as southeastern McKean County and northwestern Potter County.

To the northeast, the Richburg sand, the productive horizon of the Richburg oil pool of southern Allegany County, New York, probably lies at the same stratigraphic horizon as the Bradford Third sand. In this pool the sand has a development very similar to that in the Bradford pool, but over a smaller area.

South of the Bradford pool, the sand is again well developed in the Guffey pool along Kinzua Creek and in a small pool two miles east of Kane. This is as far south as the writer has traced the Bradford Third sand. In the Kane pool proper this sand is either poorly developed or absent. No sand was observed at its horizon in the Kane deep well. Whether the Third Bradford sand, which yields gas farther south and southwest, occurs at the same stratigraphic horizon as the Bradford Third of the Bradford district, has not yet been definitely established.

Conditions of Sedimentation

The presence of a very fossiliferous cap rock immediately above the Bradford Third sand and the sporadic occurrence of well-preserved marine fossils throughout the entire thickness of the sand body itself, indicate that the sand was deposited under marine conditions.

When the sand was laid down a shallow Upper Devonian sea covered the area. The shore line of this ancient sea probably was no very great distance to the east and southeast of the district. Streams, rendered sluggish by having to flow across a broad low-lying coastal plain that bordered this sea on the east, washed relatively fine sediments, including fine sand, silt, and clay into it. The sand accumulated in greatest volume opposite the mouths of the larger streams, and the finer material was washed farther out into the sea. Waves and shore currents, however, also played an important role in further sorting the sand from the silt and clay and distributing it more widely over the shallow sea floor near the shore. The positions of the mouths of the streams that brought in the sediments, the configuration of the sea floor, tidal currents, and the direction and strength of the littoral currents were all factors in determining the distribution, size, thickness and trends of the sand bodies as they occur today.

Oil Content

Petroleum in the pores of a reservoir rock, such as a sandstone, underneath a particular tract gives the land potential economic value. The thickness, horizontal extent, and porosity of the sandstone determine the maximum quantity of oil that it can hold, but the amount actually present may be much less. Much of the pore space may be occupied by gas or water or both. Information in regard to the extent to which the pores of the reservoir rock are actually filled with oil is, therefore, highly essential in evaluating a particular tract. Unfortunately the methods thus far developed for obtaining this type of information do not yield results that are comparable in accuracy to those attainable in connection with the determinations of porosities and permeabilities. Rough approximations, however, which are of value for purposes of comparison, are possible by present methods. The problem of developing a technique for determining accurately the actual oil content of a reservoir rock, such as a sandstone, as it occurs in place below the earth's surface, is one of such importance to the oil industry, particularly in connection with the rejuvenation of old fields, that it warrants much further careful research.

The oil content of a sandstone can be expressed in terms of the percent of its pore space that is occupied by oil. This is usually referred to as the saturation. It is, therefore, necessary to know the porosity as well as the degree of saturation in order to determine the oil content of a sand body.

For determining oil content, a core of the sand is required. For the preliminary examination, it is necessary that some one, who is familiar with this work, be present when the cores are removed from the core barrel, as there are important observations that can be made only at this time. The core is pushed out of the core barrel into a trough provided for the purpose. The samples on which the oil-content determinations are to be made must be selected as quickly as possible, wrapped in tinfoil, and placed in air-tight containers. The writer has found that quart-size paint cans with lids that fit into annular channels are the most satisfactory for this purpose. A sample just long enough to fit snugly into the can is taken. The annular channel around the circumference of the can at the top is then filled with shellac varnish and the lid is pressed tightly into position. New cans of this type can usually be secured from paint dealers or manufacturers.

After the samples for oil-content determinations have been taken and markers placed at the points from which they were removed, hot water is poured over the core, and the relative quantities of oil that ooze out from the various layers into which it is usually divided, are carefully noted. The thickness of each individual layer is measured and recorded along with a description of its characteristics and the relative quantity of oil which oozed from it. If the person who is to make the interpretation is also making the preliminary examination, he selects the samples for porosity, permeability, and other tests at the same time that these observations are made. Otherwise, the core must be boxed and shipped to him as it is important that the man who does the interpreting has an opportunity to see the entire core.

The writer has employed a method[32] for determining the oil content of core samples in which the apparatus designed by Karrick[33] for testing oil shales is utilized. The one-pint cast iron retort required can be bought from most dealers in laboratory equipment. The raised ring at the top of the retort, which forms the contact surface with the lid on the retort, as usually supplied, is machined off. The contact surfaces between the lid and the retort are then ground together by hand with very fine carborundum and water to insure a perfect fit. The retort with the lid in place is examined for leaks by surmerging it in water and forcing air, under about 15 pounds pressure per square inch, into the delivery tube. A gasket of thin asbestos paper coated on both sides with a paste of glycerine and very fine graphite is inserted between the top of the retort and the lid in making tests.

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[32] Chas. R. Fettke, Core studies of the Second sand of the Venango group from Oil City, Pa.; Petroleum Development and Technology in 1926, Am. Inst. Min. Eng., page 229, 1927.

When everything is ready for a test, the core sample is removed from the air-tight container and a length just sufficient to fill the retort snugly when crushed, is selected. This is quickly broken up into small fragments, none of which exceed one-half inch in thickness, weighed in a beaker, and transferred to the retort. It is important that the retort be completely filled. A representative fragment is laid aside for a porosity determination. A low flame is applied at the start so that the first gasoline and water begin to come off at the end of 20 minutes. The heat is increased thereafter every 15 minutes by raising the flame until, at the end of about 2½ hours, the whole retort has been brought to a dull red heat. The iron delivery tube is then warmed with a Bunsen burner to aid in draining any oil or water still remaining in it. The volumes of the oil and water which have collected in the graduated cylinder are then read and recorded. After cooling, the sample is again weighed and the loss in weight checked against the volume of oil and water recovered.

Some cracking of oil takes place in the retort. A correction factor is applied for this loss, which is obtained by charging the retort with dry sand in which measured volumes of oil, similar to that in the core, and water, approximately equal to the quantities obtained from the samples, have been thoroughly incorporated. This charge is heated in exactly the same manner that the samples are treated and the percent of oil lost by cracking is thus determined. With Bradford crude oil, the recovery was found to be 86.7 percent when the procedure as outlined was followed.

A small correction factor should also be applied to the water recovered Most oil sands contain at least small amounts of hydrated minerals, such as chlorite, kaolinite, limonite, and sericite, which yield some water at the high temperatures to which the sample is subjected during the test. In the case of a typical Bradford Third sand sample, the yield of combined water was found to be 0.89 percent by weight of the sample. An equivalent volume of water was, therefore, deducted from the water recovered.

Knowing the density of the sample from a Melcher porosity determination made on a representative fragment and its total weight, the total volume of the sample can be calculated. Multiplying this by the percent of porosity gives the total pore space. Dividing the corrected volume of oil by the total pore space gives the percent of the total pore space in the sample that was occupied by oil. This represents the percent of saturation.

The results obtained give only an approximate idea of the actual oil content of the sand in the ground. They give a minimum figure; the actual oil content may be considerably greater. In cores taken with the diamond drill, some loss of oil, no doubt, takes place at the cutting edge of the bit as it penetrates the sand, owing to the tendency of the water under pressure to penetrate the sand just ahead of the bit, particularly in old fields where the gas pressure is low. Although the water in the hole is not under pressure when the cable-tool core barrel is used, the breaking up of the sandstone into biscuits exposes a much larger surface for the oil to escape from and for water to penetrate the pores and displace oil. The samples from this type of core usually contain more water than those taken with the diamond drill. In a few cases where the writer has had an opportunity to test samples taken by both methods from the same sand in the same district, about the same percentage of the pore space of the sand was found to be occupied by oil. All the cores of the Bradford Third sand described, except No. 13, were taken with a cable-tool core barrel.

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[33] L. C. Karrick, Manual of testing methods for oil shale and shale oil: U. S. Bur. Mines Bull. 249, p. 7, 1926.

Some seepage and evaporation losses occur, no doubt, while the sample is being transferred from the core barrel to the container and while it is in storage. There is also a slight unavoidable loss after it is removed and while being crushed for testing. The samples should be tested as soon as possible after they have been taken in the field.

The results of oil-content determination on samples from seven of the 21 cores of Bradford Third sand described are tabulated in Table 38.

Table 38. Oil and water content of samples from seven cores of Bradford Third sand.

Core number and position of sample in core Depth in feet	Bulk density of sandstone after extraction and drying	Total pore space by volume Percent	Percent of total pore space		
			Occupied by oil	Occupied by water	Not occupied by oil or water
Core 2.					
1426.48	1.986	25.2	11	48	41
1428.88	2.213	16.5	14	71	15
1446.12	2.271	14.5	29	56	15
1448.74	2.235	15.8	29	71	0
Core 3					
1778.95	2.254	15.1	20	77	3
1783.20	2.309	13.4	33	67	0
1811.45	2.302	14.1	34	49	17
1819.70	2.294	14.2	42	58	0
Core 9.					
1737.58	2.266	14.8	51	49	0
1739.75	2.257	15.0	48	52	0
1742.25	2.245	15.7	11	52	1
1762.21	2.335	12.4	43	57	0
1785.25	2.331	12.9	34	38	28
1786.15	2.298	13.7	41	39	20
1787.15	2.360	12.8	45	51	4
Core 16.					
1680.67	2.085	21.8	65	35	0
Core 17.					
1973.65	2.252	15.7	49	51	0
1977.95	2.322	13.3	45	55	0
1980.25	2.271	15.0	34	40	26
Core 19.					
2032.36	2.329	13.0	42	30	28
2036.50	2.341	12.2	48	42	10
2044.58	2.299	13.9	39	46	15
2051.32	2.026	23.9	39	61	0
2056.32	2.257	15.3	64	36	0
2067.29	2.228	16.5	36	36	28
Core 21.					
1908.00	2.310	13.2	38	31	31
1934.28	2.313	13.7	48	46	6

The tests show that almost all the samples contain more water than oil. As all the cores were taken in areas not yet reached by flood waters, and the sand itself, except around the edges of the pool, yields little or no salt water, the question arises as to the source of this water. In order to obtain some information in regard to the nature of the water, the total soluble salt content of a sample from a depth of 1742.25 feet in core 9 and from 1680.67 feet in core 16 was determined. Of core 9, 200 grams yielded only 0.1120 grams of soluble salts and 200 grams of core 16, 0.1760 grams. Assuming that all these salts were in solution in the water in the pores of the sample, which is not necessarily the case, the concentration in core 9 would be only 1.5 percent and in core 16 2.4 percent. In contrast, connate water in the Bradford Third sand on the edges of the pool has a concentration of 13.1 to 15.8 percent and the first water produced from an oil well affected by a water-drive, from 7.7 to 13.4 percent. It would seem safe to assume, therefore, that most of the water in the samples entered during the drilling operation, probably not more than 20 percent represented water originally in the sand.[34] No attempt was made to remove any water from the surfaces of the samples when they were taken from the core barrel or afterwards, as this would have entailed the loss of some oil. Part of the water, therefore, represents that adhering to the surface of the sample.

The oil content per acre of the Bradford Third sand has been estimated from the data presented in Table 38 for six of the cores. This is shown in Table 39. The following formula was used:

Oil content per acre in barrels = 7,758 x thickness of sand in feet x percent porosity x percent saturation.

Table 39. Oil content per acre of Bradford Third sand, shown by six core analyses.

Core number and portion of sand included	Thickness in feet	Average total porosity Percent	Average saturation Percent	Oil content per acre Barrels
Core 2				
Gas "pay"	13.27	16.7	12.5	2,150
Oil "pay"	20.17	13.9	29.0	6,310
Core 3				
Gas "pay"	6.30	15.6	20.0	1,525
Oil "pay"	34.10	14.3	36.3	13,730
Core 9				
Top "pay"	24.57	14.4	46.5	12,765
Bottom "pay"	11.21	13.7	40.0	4,770
Total				17,535
Core 17				
Entire sand body	21.27	14.8	42.7	10,430
Core 19				
Upper portion	18.26	12.7	43.0	7,735
*Middle portion	7.44	23.3	39.0	5,245
Lower portion	18.11	14.9	50.0	10,470
Total				23,450
Core 21				
Entire sand body	28.50	12.8	43.0	12,170

*Loose streak

Although the core tests give only minimum figures, in estimating oil reserves the writer is convinced from numerous core analyses checked against actual production figures, that there is no justification for the assumption that the entire pore space of oil sands in the Appalachian fields was necessarily occupied by oil originally, and that by deducting the quantity of oil already recovered from a particular tract, the remaining reserve can be estimated from the total pore space available in the sand. In core 9, for example, there is sufficient pore space to have contained 39,360 barrels per acre. The natural production from this area did not exceed 5,000 barrels per acre, leaving 34,360 barrels still to be accounted for if 100 per cent saturation is assumed. The core tests show only 17,535 barrels or approximately half this amount. It is hardly conceivable that this difference can be accounted for by shrinkage in volume due to loss of gas originally held in solution and losses incurred in the coring operation and the testing of the samples.

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[34] Alex. W. McCoy and W. Ross Keyte, Present interpretations of the structural theory for oil and gas migration and accumulation: Problems of Petroleum Geology, Am. Assoc. Petroleum Geologists, pp. 285-286, 1934.

OIL AND GAS SANDS ABOVE THE BRADFORD THIRD

Bradford First Sand

The early drillers thought that the oil which they had discovered in the Bradford Third sand along the Tunungwant valley above Foster Brook came from the same geological horizon as that occupied by the Third sand along Oil Creek in Venango County. They, therefore, called the first sand met in drilling for the latter, the First sand on the assumption that since there were three oil sands in the Venango district there must be three in the Bradford region. Before it was learned that the Bradford Third sand lies about 1,250 feet stratigraphically below the Third sand of the Venango district, this nomenclature had become so firmly established that it has been retained to the present day.

In the Bradford district the average interval between the top of the Bradford First and the top of the Bradford Third sand is 610 feet. The minimum is about 560 feet and the maximum 658 feet. Although this sand is only occasionally recorded by the drillers, examination of complete sets of drill cuttings almost invariably shows some sandstone at this horizon. The sand occupies the same stratigraphic position as the Cuba sandstone on the outcrop in New York State.

In the northern part of the Bradford field along Nichol Run and the area immediately adjacent to the south and east, the Bradford First sand consists of about ten feet of medium- to coarse-grained light-gray to white sandstone with quartz grains up to 2 millimeters in diameter. It is somewhat calcareous in the upper part and usually carries salt water that has to be cased off. In other parts of the field the sandstone is much finer grained. A little salt water, not sufficient to necessitate the setting of casing, and slight shows of gas are occasionally reported. Nowhere in the district has this horizon been the source of commercial quantities of gas or oil.

Sugar Run Sand

The Sugar Run sand is the productive horizon in the Sugar Run pool, also called the Watsonville, three miles west of the Bradford pool. In this area the sand is usually separated into two parts. The upper bed, three to eight feet thick, consists of a medium-grained white quartz sandstone. The production west of Klondike in Corydon Township comes from this bed. Ten to 20 feet below it is a lower hard light-gray quartz sandstone, 60 to 80 feet thick, the lower 10 to 20 feet of which also produce oil locally. The upper "pay" is sometimes called the Watsonville sand and the lower the Dewdrop.

In the Bradford district a fine to very fine-grained light greenish-gray to brownish-gray sandstone frequently occurs at this horizon, but on account of the small interval between it and the overlying Bradford First and the underlying Chipmunk, it is usually logged as one or the other of these two sands. The average interval between the top of the Sugar Run and the top of the Bradford Third in the district is 525 feet, the minimum observed being 483 feet and the maximum 559 feet. Small shows of gas, oil and salt water are found locally at this horizon but no commercial production has been obtained from it.

Chipmunk Sand

The Chipmunk oil pool, north of the Bradford, along Chipmunk Creek in the Town of Carrollton, Cattaraugus County, New York, is the type locality for the Chipmunk sand. In this area it has yielded considerable quantities of oil. Several large rock fragments recovered in cleaning out an old well in this pool consisted of fine-grained light grayish-brown sandstone and possessed porosities up to 22.5 percent. A screen analysis of one of these fragments is given in Table 40.

Table 40. Screen Analyses of Chipmunk, Bradford Second and Lewis Run sands

Size of openings Milliameters		Chipmunk sand from Chipmunk pool Percent	Bradford Second sand from Bennett Brook Percent	Lewis Run sand from Edson 5 core. Depth 1477.20 feet Percent	Lewis Run sand from Edson 5 core. Depth 1481.25 feet Percent
Through	Caught on				
.295	.208	0.3	2.3	0.1	0.1
.208	.147	7.2	12.6	3.8	6.9
.147	.104	49.4	30.4	25.1	27.5
.104	.074	31.5	34.8	31.0	35.6
.074	.061	3.4	6.0	8.8	8.2
.061	.043	3.2	5.4	10.8	8.5
.043		4.9	8.4	20.3	13.0
Average grain diameter—millimeters		.056	.048	.036	.043
Porosity percent		22.5	16.1	12.9	16.0

In the Bradford district the average interval between the top of the Chipmunk and the top of the Bradford Third sand is 440 feet. The minimum observed was 384 feet and the maximum, 484 feet.

Drill cuttings of the Chipmunk sand from the Cochran No. 130 well of the Nichol Run Oil Company (locality 2, Plate D), and the Mayrock B-12 well of the Bradford Producing Company (near locality 7), were obtained for examination. In the former well the sand has a total thickness of 43 feet. The upper 8½ feet consist of medium to coarse-grained light-gray quartz sandstone with some white quartz pebbles up to 4 millimeters in diameter; the next 8½ feet, medium-grained light-brown sandstone; and the rest of the sand body is fine-grained and light brown. The sand yields oil at this locality. In the latter well the sandstone is 25 feet thick. With the exception of a thin layer of light-gray sandstone at the base, the color is light brown. The texture is finer and the sandstone is more calcareous than at the first locality. No fluids were encountered in it. The proportions of sandstone present at the two localities are given in Table 41 and are shown graphically in Figure 27.

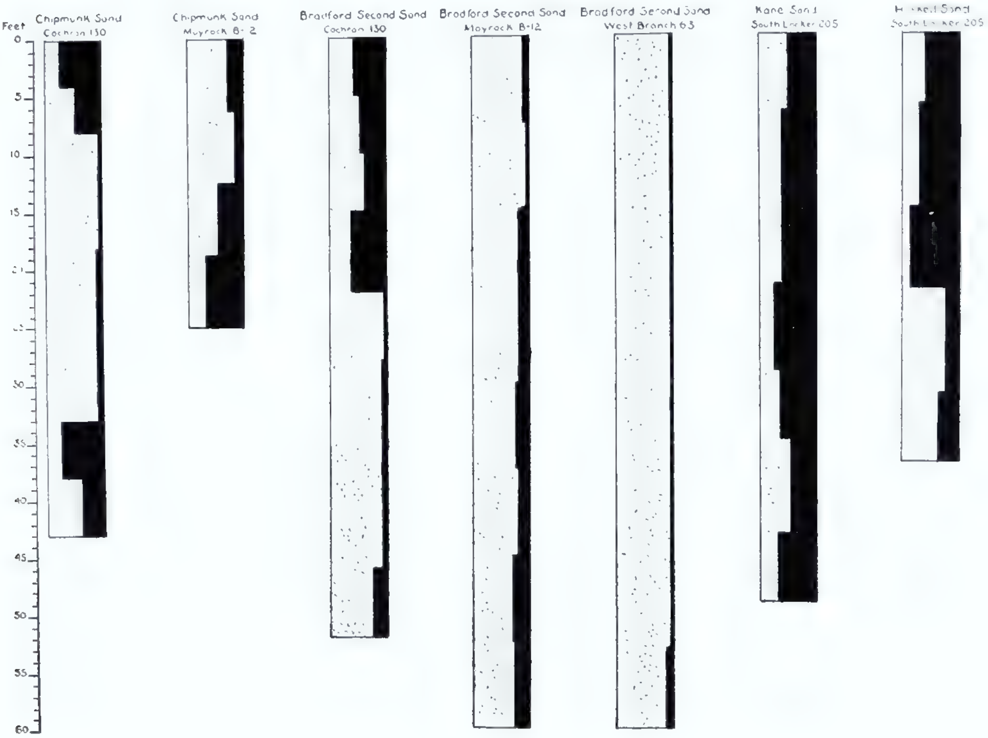

FIGURE 27. **Proportions of sandstone and shale in the Chipmunk, Bradford Second, Kane, and Haskell sands at four localities in the Bradford district.**

Table 41. Proportions of sandstone in the Chipmunk sand in Cochran No. 130 and Mayrock B-12 wells.

COCHRAN NO. 130 WELL.
Depth top, 1411 feet

Screw	Length of screw feet	Sandstone feet
1	4.0	2.1
2	4.0	3.8
3	5.0	4.8
4	5.0	4.5
5	5.0	4.5
6	5.0	4.5
7	5.0	1.2
8	5.0	3.3
9	5.0	3.1
	43.0	31.8

74 percent sandstone

MAYROCK B-12 WELL.
Depth top, 935 feet.

Screw	Length of screw feet	Sandstone feet
1	6.25	4.5
2	6.25	5.3
3	6.25	3.7
4	6.25	2.0
	25.0	15.5

62 percent sandstone

South of the pool the Chipmunk sand produces oil on Nichol Run along the northern margins of the Bradford pool. A little oil has also been recovered from it along the Tunungwant valley below Foster Brook and some gas west of the borough of Lewis Run.

Bradford Second Sand

The Bradford Second sand was the second sand found along the Tunungwant by the early drillers who were looking for the "Third" sand of the Venango district, hence the name. The average interval between the top of this sand and the top of the Bradford Third is 325 feet; the minimum observed, 284 and the maximum, 390. It is probably the most persistent of the sands above the Bradford Third, but changes considerably in lithological character from east to west.

Drill cuttings of this sand were obtained from the Cochran No. 130 and the Mayrock B-12 wells, and also from West Branch No. 63 well of S. J. George (near loc. 90, pl. D). In the Mayrock B-12 well the sand has a total thickness of 60 feet. It consists of a fine to very fine-grained grayish-brown sandstone with considerable interbedded shale. The sandstone is somewhat calcareous throughout and particularly so in the lower part. It was dry. In the Cochran No. 130 well the sandstone is 52 feet thick. It consists of a fine grained chocolate-brown sandstone, somewhat coarser than that in Mayrock B-12 well. The upper 15 feet have considerable shale interbedded with the sandstone and yield only gas. The lower 37 feet are oil-bearing. In the West Branch No. 63 well the sand is 60 feet thick and remarkably free from interbedded shale. The upper 46 feet consist of medium- to coarse-grained light gray, nearly white quartz sandstone with some well rounded quartz pebbles up to 4 millimeters in diameter and a few red jasper grains. The lower 14 feet are light brown. The sandstone is only slightly calcareous, but appears to be thoroughly cemented by secondary silica. The deposition of silica has developed crystal facets on some of the grains. Only a little oil was obtained from it in this well. The proportions of sandstone present at the three localities are given in Table 42 and are shown graphically in Figure 27.

Table 42. Proportion of sandstone in the Bradford Second sand in Mayrock B-12, Cochran No. 130 and West Branch No. 63 wells.

MAYROCK B-12
Depth top, 1105 feet

Screw	Length of screw feet	Sandstone feet
1	7.5	6.7
2	7.5	7.1
3	7.5	6.1
4	7.5	5.9
5	7.5	5.7
6	7.5	5.8
7	7.5	5.1
8	7.5	5.4
Total	60.0	47.8

71 percent sandstone

COCHRAN No. 130
Depth top, 1530 feet

Screw	Length of screw feet	Sandstone feet
1	5	2.1
2	5	2.7
3	5	3.0
4	7	2.5
5	6	5.7
6	6	5.4
7	6	5.4
8	6	5.4
9	6	4.5
Total	52	36.7

71 percent sandstone

WEST BRANCH No. 63
Depth top, 1439 feet

Screw	Length of screw feet	Sandstone feet
1	8	7.7
2	8	7.6
3	7	6.6
4	6	5.7
5	9	8.5
6	8	7.6
7	7	6.6
8	7	5.9
Total	60	56.2

94 percent sandstone

A large fragment of Bradford Second sand recovered after a shot, from a well in the small Second sand pool near the mouth of Bennett Brook, consisted of moderately friable, fine-grained light grayish-brown sandstone. It possessed a porosity of 16.1 percent. A screen analysis is included in Table 40.

The Bradford Second sand has yielded oil along Nichol Run in the northern part of the Bradford district and in several small areas in the western part of the field along Bennett Brook, the West Branch of Tunungwant Creek, and Marilla Brook. A little oil has also been obtained from it south of the

Erie Railroad station at Lewis Run. In the area northwest of the Bradford oil pool small gas pools have been discovered in it. The gas is usually confined to the upper few feet of sand, most of the sand body containing salt water. Over most of the Bradford district the Bradford Second is a dry sand. Only occasionally are small shows of gas, oil or salt water observed at this horizon.

Harrisburg Run Sand

A thin, not very persistent, fine-grained grayish-brown to chocolate-brown sandstone occurs about 100 feet below the horizon of the Bradford Second sand, for which the writer proposes the name Harrisburg Run because some oil production has been obtained from it at the head of Harrisburg Run in the northern part of the Bradford district. The interval between the top of this sand and the top of the Bradford Third ranges from 178 to 271, average 230 feet. On account of the relatively small interval between it and the Bradford Second, the Harrisburg Run sand is usually logged under the latter name when noticed by the drillers. Examinations of complete sets of drill cuttings, however, show that frequently both sands are present in the same area.

A core of the Harrisburg Run sand was taken in the Summit K-9 well of the Sloan and Zook Producing Company (loc. 83, Plate D). A description of the section revealed by this core is given in Table 43 and the porosities of its component sandstone layers are shown in Table 44. A graphic section of the sand and its porosity profile are included in Figure 28.

Table 43. Section of Harrisburg Run sand from Summit K-9 well.

Thickness feet	Description of strata	Depth in feet	
		Top	Bot.
	Top of Harrisburg Run sand	1330.7	
1.8	Sandstone, hard, fine-grained, chocolate-brown	1330.7	1332.5
1.0	Shale, with occasional thin seams, hard, fine-grained, chocolate-brown sandstone	1332.5	1333.5
.5	Sandy shale	1333.5	1334.0
1.0	Shale	1334.0	1335.0
.4	Sandy shale	1335.0	1335.4
.2	Sandstone, hard, fine-grained, chocolate-brown	1335.4	1335.6
1.4	Sandy shale, sparingly fossiliferous	1335.6	1337.0
1.6	Sandstone, hard, fine-grained, chocolate-brown (fair show of oil)	1337.0	1338.6
.3	Shale, with interbedded seams, hard, fine-grained, chocolate-brown sandstone	1338.6	1338.9
.2	Sandstone, hard, fine-grained, chocolate-brown (slight show of oil)	1338.9	1339.1
2.0	Shale, with interbedded thin seams hard, fine-grained, chocolate-brown sandstone	1339.1	1341.1
.2	Sandstone, hard, fine-grained, chocolate-brown	1341.1	1341.3
1.2	Shale, with interbedded thin seams, hard, fine-grained, chocolate-brown sandstone	1341.3	1342.5
.5	Shale, fossiliferous	1342.5	1343.0
1.0	Shale, with interbedded thin seams, hard, fine-grained, chocolate-brown sandstone	1343.0	1344.0
.2	Sandstone, hard, fine-grained, chocolate-brown	1344.0	1344.2

Table 44. Total pore space by volume of seven samples of Harrisburg Run sand from Summit K-9 well.

Depth	Percent	Depth	Percent
1330.9	3.5	1338.6	9.8
1331.7	4.0	1341.3	2.7
1335.5	3.1	1344.0	3.8
1337.5	12.4		

OIL AND GAS SANDS BELOW THE BRADFORD THIRD

Lewis Run Sand

The reservoir rock in the Lewis Run pool, in the borough of Lewis Run and the area immediately to the southwest, is the Lewis Run sand, a thin, fine-grained chocolate-brown sandstone. In this pool the sandstone ranges in thickness from 6 to 12 feet, and has yielded both gas and oil.

The sand occurs also under parts of the Minard Run valley to the northeast and is occasionally found in wells still farther northeast in the center of the Bradford pool, where small shows of gas and oil are sometimes obtained from it.

The observed interval between the top of the Lewis Run sand and the top of the Bradford Third ranges from 64 to 168 feet, averages 100 feet.

A section of the Lewis Run sand was obtained from a core taken in the Edson No. 5 well (loc. 155, Plate D). This is given in Table 45 and is shown graphically in Figure 28 along with a porosity profile. The porosities of four samples of the sandstone from this core are given in Table 46, and screen analyses of two samples are included in Table 40.

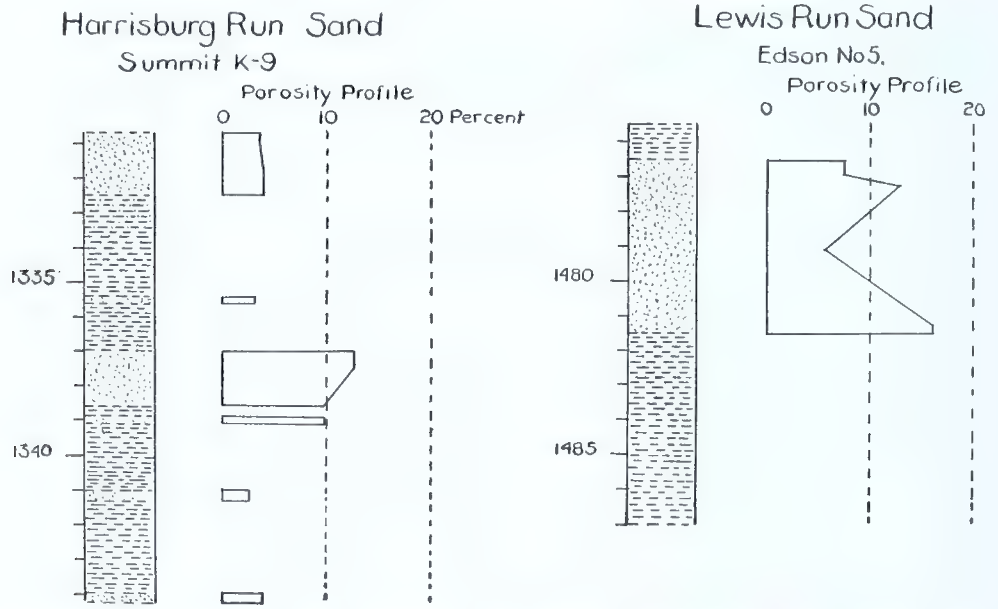

FIGURE 28. **Sections and porosity profiles of Harrisburg Run sand from Summit K-9 well and Lewis Run sand from Edson No. 5 well.**

Table 45. Section of Lewis Run sand from Edson No. 5 well.

Thickness feet	Description of strata	Depth in feet Top	Depth in feet Bot.
1.2	Shale	1475.5	1476.7
4.8	Hard to moderately hard, fine-grained chocolate-brown sandstone containing marine fossils (show of oil)	1476.7	1481.5
5.5	Shale	1481.5	1487.0

Table 46. Total pore space by volume of four samples of Lewis Run sand from Edson No. 5 well.

Depth	Percent	Depth	Percent
1476.95	7.4	1479.10	5.6
1477.20	12.9	1481.25	16.0

Kane Sand

That the Kane sand of the Bradford district occurs at about the same stratigraphic horizon as the Kane sand of the Kane field has been shown by the series of well sections plotted in Plate 9. The observed interval between the top of this sand and the top of the Bradford Third ranges from 184 to 309 and averages 240 feet.

Samples of the drill cuttings from this sand were obtained from the South Looker No. 205 well of the Petroleum Reclamation Company (loc. 126, Plate D). The sand is 49 feet thick in this well, but contains much interbedded shale. The sandstone layers are fine textured, chocolate-brown, and are somewhat calcareous in the upper part. The sand was dry. The proportion of sandstone is given in Table 47 and shown graphically in Figure 27.

Table 47. Proportion of sandstone in the Kane sand in South Looker No. 205 well.

Depth top, 1538 feet

Screw	Length of screw feet	Sandstone feet	Screw	Length of screw feet	Sandstone feet
1	6.5	3.3	6	8.0	4.1
2	7.5	2.9	7	6.0	1.8
3	7.5	2.8			
4	7.5	1.7		Total 49.0	18.6
5	6.0	2.0			

38 percent sandstone.

The Kane sand has been a prolific source of gas and some oil in the Ormsby pool, southeast of the Bradford oil pool. It has also yielded some gas in the extreme southern part of the Bradford pool and at the northeastern edge of the Guffey or Kinzua Creek pool. A good show of oil was reported from this horizon in the Quinlan deep well near the head of Indian Creek in the northeastern part of the Bradford district.

Haskell Sand

The Haskell sand was so-named because oil was found at this horizon in the Haskell well drilled in 1877 on the east side of Marvin Creek, southwest of Smethport. This well was still producing a little oil in 1929. In the Bradford district the observed interval between the top of this sand and the top of the Bradford Third ranges between 408 and 511, averages 450 feet.

Samples of the drill cuttings from this sand were also obtained from the South Looker No. 205 well. The sand at this locality measures 37 feet, but contains much interbedded shale. The sandstone has a fine texture and a chocolate-brown color. It is somewhat calcareous. A little gas was present in the lower layers. The proportion of sandstone is given in Table 48 and is shown graphically in Figure 27.

Table 48. Proportion of sandstone in the Haskell sand in South Looker No. 205 well.

Depth top, 1701 feet

Screw	Length of screw feet	Sandstone feet	Screw	Length of screw feet	Sandstone feet
1	6.0	2.3	5	6.0	3.8
2	9.0	2.5			
3	7.0	0.8		Total 37.0	16.0
4	9.0	6.6			

43 percent sandstone.

Besides the small amount of oil production along Marvin Creek, the Haskell sand has yielded some gas south of Rixford in the eastern part of the Bradford pool. This sand is an important source of gas southeast of the Bradford district in southeastern McKean County, where it is known as the Elk sand.

DEEP SANDS

Since the recent discoveries of gas in the Oriskany sandstone of the Lower Devonian in north-central Pennsylvania, it has become customary to refer to the productive sands of the Upper Devonian and higher strata as the shallow sands. The Oriskany and lower possible oil and gas horizons are spoken of as the deep sands.

Oriskany Sandstone

Early in the present century a small gas pool was opened in the vicinity of Austinburg in northeastern Ohio in a sandstone occurring at the Oriskany horizon. In 1925, gas in commercial quantities was found in the Oriskany sandstone northwest of Cambridge in Guernsey County, Ohio, and a few years later a small oil pool in the same formation southwest of Cambridge. The discovery of relatively large volumes of gas in the Oriskany sandstone in the Wayne-Tyrone pool in Schuyler County, New York, in March, 1930; in the Tioga pool in Tioga County, Pennsylvania, in September, 1930; and the Hebron pool in Potter County, Pennsylvania, in November, 1931, however, has focused attention upon this formation as a potential source of gas and possibly of oil.

In the Bradford district, the Oriskany sandstone at the end of 1935 has already been tested by three wells for its gas and oil possibilities in the Knapp Creek dome. The first of these wells is along Foster Brook near Derrick City (loc. 7, Plate 11). Here the top of the Bradford Third sand is 456 feet above sea level and the top of the Oriskany sandstone 2,559 feet below sea level. The drillers logged 20 feet of sandstone with a show of oil. A single sample from this horizon on file at the office of L. E. Mallory in Bradford is typical Oriskany sandstone. The well is about 1½ miles southeast of the axis of the Bradford anticline, as shown on Plate E.

The second well was drilled on the Quinlan property near the head of Indian Creek in New York State (loc. 5, Plate 11). Here the top of the Bradford Third sand is 546 feet above sea level and the top of the Oriskany sandstone 2,590 feet below sea level. The well is about ¼ mile north of the axis of the Bradford anticline and very near the top of the Knapp Creek dome with reference to the Bradford Third sand. The writer has examined the drill cuttings from this well. The Oriskany sandstone is 15 feet thick. A good show of oil and a little gas is said to have been found in it. Although the sand was shot, it did not make a commercial producer.

The third well was drilled on the Ryder-Scott property at the head of Chipmunk Run in New York State (loc. 6, Plate 11). The top of the Bradford Third sand in this well is 457 feet above sea level and the top of the Oriskany sandstone 2,477 feet below sea level. The well is about 1¼ miles north of the axis of the Bradford anticline. Drill cuttings from this well showed 17 feet of typical Oriskany sandstone. Neither gas, oil nor salt water was reported from this horizon.

Only drill cuttings of the Oriskany sandstone were available for examination from the three wells. These show it to be a medium-grained light-gray quartz sandstone. All had some calcium carbonate as a bond between the sand grains, as well as secondary silica, deposited on the original quartz grains. Both the calcium carbonate and the secondary silica have reduced the porosity of the rock. The fact that no fluids were reported in one of the wells and only small quantities of oil and a little gas with no water in the other two, also indicates that the porosity of the sandstone must be low.

The Quinlan well is about 4¼ miles east of the Ryder-Scott and the Derrick City well about 3¾ miles southwest. Although the Quinlan well was highest on the structure with respect to the Bradford Third sand, the top of the Oriskany in it was the lowest of the three wells. This is due to apparent changes in the interval between the top of the Bradford Third sand and the Oriskany. In the Quinlan well this interval is 3,136 feet, in the Derrick City well it is 3,015, and in the Ryder-Scott only 2,834. To what extent this difference may be due to crooked holes cannot be determined as none of the wells have been surveyed for deviation from the vertical. Actually the interval does thin toward the northwest. In the Zerbe well (loc. 8, Plate 11), 15 miles southeast of the Derrick City well, it is 3,585 feet as compared to 3,015 in the latter well. This shifts the axis of the structure on the Oriskany in a northwesterly direction also.

Deep drilling has shown that the Oriskany sandstone probably extends only a short distance beyond the northwestern limits of the Bradford field and that it is also absent from that part of McKean County immediately southeast of the district. The approximate boundaries are shown on Plate 11.

Lockport Dolomite

Gas and oil were discovered in 1911 in a granular porous dolomite in the Niagara limestone at South Newburg in the southern part of Cleveland, Ohio. This horizon has since been called the Newburg "sand." At the type locality it occurs about 250 feet below the top of the Niagara limestone, which corresponds closely in geologic age to the Lockport dolomite of western New York and northwestern Pennsylvania.[35] The Newburg sand proved productive at several localities in Ohio.

The Lockport dolomite underlies the entire Bradford district. In the Derrick City deep well the dolomite occupies the interval between 5,085 and 5,385 feet. A small show of oil was reported in it between 5,130 and 5,176 feet. North of the Bradford district in the Autman well (loc. 4, on Plate 11) salt water occurs in the Lockport, 96 feet below the top.

Medina Sandstone

The sandstones of the Medina group have been the great source of gas in western New York and central Ohio. Oil has also been obtained from them in central Ohio.

The Medina sandstones undoubtedly underlie all of the Bradford district. In the Derrick City deep well the Red Medina occupies the interval from 5,560 to 5,642 feet and the White Medina, from 5,642 to 5,700 feet. At this locality the sandstone apparently has been so tightly cemented by metamorphism that it is incapable of holding any fluids, either gas, oil, or water, as none were found in it. The same condition exists in the Autman well north of the Bradford district and the Kane deep well to the south. Two fragments obtained from the White Medina sandstone in the Kane deep well of the United Natural Gas Company (loc. 10, Plate 11) had total porosities of only 3.3 and 3.6 percent by volume.

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[35] Frank R. Van Horn, Economic geology of the Cleveland district, Ohio: U. S. Geol. Survey, Bull. 818, pp. 117-120, 1931.

Trenton Limestone

Large quantities of oil and gas have been obtained from the Trenton limestone in the Lima-Indiana field in northeastern Indiana and northwestern Ohio. The oil and gas occur in the upper 100 feet of the formation. This part of the limestone was made porous by dolomitization and the oil and gas accumulated where the structural conditions were favorable. No production of consequence, however, has been discovered in the Trenton limestone in Ohio outside the above field. In New York, gas flows of sustained volume have been found in the Trenton limestone in wells at Baldwinsville, Onondaga County, and at Fulton, Pulaski and Lacona, Oswego County, in the central part of the state.

All the above occurrences are far from the Bradford district and hence afford little information about the possibilities of finding commercial quantities of gas or oil in the Trenton limestone in this area. The Trenton horizon probably is represented by a limestone. Whether any of it is sufficiently porous to act as reservoir rock for the accumulation of gas or oil is problematic. The deep tests to this horizon nearby in New York have not been encouraging.

In southern Erie County in western New York State, the interval between the base of the White Medina (top of the Queenston shale) and the top of the Trenton limestone in two wells is 1,830 and 1,857 feet.[36] According to Butts,[37] 2,650 feet of strata occupy the interval between the top of the Juniata formation (Queenston) and the top of the Trenton limestone where these formations crop out in Blair and Huntingdon Counties in central Pennsylvania. Apparently, as with the higher beds, some thickening of the interval between the base of the Medina sandstones and the top of the Trenton limestone occurs in a southeasterly direction. In the Bradford district it is estimated that the top of the Trenton limestone lies about 6,600 feet below the top of the Bradford Third sand.

PHYSICAL AND CHEMICAL CHARACTER OF CRUDE PETROLEUM

For purposes of comparing the characteristics of the crude petroleum from the Bradford Third sand from different parts of the Bradford pool and the smaller pools adjacent to it, as well as the crude produced from sands above and below the Bradford Third horizon, 21 samples were collected. Each sample was taken from the lead line as the well was pumping. The samples were shipped in gallon tin cans to the U. S. Bureau of Mines station at Bartlesville, Oklahoma, where they were analyzed according to standard procedure by petroleum chemists of that organization.

The sources of the 21 samples are given in Table 49; their characteristics, in Table 50; their distillation characteristics, in Table 51; and a summary of their fractionation, in Table 52.

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[36] D. H. Newland and C. A. Hartnagel, Review of the natural gas and petroleum developments in New York State: New York State Mus. Bull. 295, p. 122, 1932.

[37] Charles Butts, Geologic section of Blair and Huntingdon Counties, central Pennsylvania: Am. Jour. Sci, 4th Ser., vol. 46, pp. 536-537, 1916.

Table 49. *Sources of 21 samples of crude petroleum from Bradford Field and adjacent areas.*

Sample number	Operator	Property and well number	Sand	Pool	Township	County	State	Elevation top of well, feet	Depth to top of sand, feet	Total depth of well, feet	Date drilled	Production at time of sampling barrels	Date collected	Collector of sample
1	Bradford Producing Co.	Mayrock 47	Bradford Third	Bradford	Olean	Cattaraugus	New York	1766	1258				July 29 1929	Fettke
2	Pressure Oil Co.	Artley 71	do	do	Otto	McKean	Pennsylvania	2233	1771	1881	Aug. 1928		July 8 1929	do
3	Petroleum Reclamation Co.	Hawkins-Bryner 22	do	do	Bradford	do	do	2192	1797	1899		Oil ½ Water 2¾	July 1926	Newby
4	Petroleum Reclamation Co.	Hawkins-Bryner 11	do	do	do	do	do	2198	1799	1868		Oil ¾ Water 1¾	July 1926	do
5	Petroleum Reclamation Co.	Hawkins 1-C-5	do	do	do	do	do	2197	1799	1823	July 1925	Oil 1¾ Water 9	July 1926	do
6	Petroleum Reclamation Co.	Hawkins-Bryner 10	do	do	do	do	do	2216	1817	1877		Oil 6 Water 18	July 1926	do
7	Healy Petroleum Corp.	G-19	do	do	do	do	do	2183	1835	1912	May 1929		June 29 1926	Fettke
8	T. H. Kennedy	Connolly 174	do	do	Keating	do	do	2216	1959	2014	March 1929	Oil 3	July 1 1929	do
9	Johnston and Matthews	Bingham 113	do	do	Lafayette	do	do	2146	2030	2056	March 1929	Oil 2	June 24 1929	do
10	Hilltop Oil Company	Watson 26	do	do	do	do	do	2152	2079	2109	June 1917		Sept. 7 1929	do
11	Rich and Company	Cole 6	do	Minard Run	Bradford	do	do	1617	1317	1417	July 1929		Sept. 12 1929	do
12	Simpson Brothers	Emery and Simpson 31	do	Guffey	Lafayette	do	do	2096	2020	2062			Aug. 20 1929	do
13	Letson and Smith	Letson 1	do	Windfall	Eldred	do	do	1529	1205	1262	Jan. 1929		Aug. 11 1930	do
14	H. L. Stoner	Irons Estate 4	do	Marvin Creek	Keating	do	do	1542	1292	1325			Aug. 26 1929	do
15	Messer Oil Corp.	Shaner A-50	Richburg	Richburg	Bolivar	Allegany	New York	1860	964	1039	Feb. 1928	Oil 8	July 5 1929	do
16	L. E. Mallory and Son	Hemlock 23 (Warrant 3705)	Sugar Run	Sugar Run	Corydon	McKean	Pennsylvania	2077	1404	1437			Aug. 17 1930	do
17	S. J. George	West Branch 61	Bradford Second	Marilla Brook	Bradford	do	do	2113	1413	1513	July 1929		Sept. 9 1929	do
18	F. J. Rider	Rider 28	do	Bennett Brook	do	do	do	1619	917	980			Sept. 13 1929	Copeland
19	Wood, Kennedy and Co.	Lewis Run 48	Lewis Run	Lewis Run	Lafayette	do	do	1605	1448	1478	Aug. 1919		Sept. 16 1929	Fettke
20	Eugene Connors	Connors 1	Kane	Ormsby	Keating	do	do	1791	1958	1972			Sept. 16 1929	do
21	Sloan and Zook Company	Indian 12	Kane	Kane	Highland	Elk	do		2370 apprx.			Oil ¼	Aug. 28 1930	do

Table 50. Characteristics of 21 samples of crude petroleum from Bradford Field and adjacent areas.

Sample Number	Sand	Color	A. P. I. gravity, degrees	Viscosity at 100° F. Saybolt Seconds	Pour point Degrees F.	Sulphur Percent	First drop Degrees C.	Carbon residue of crude. Percent
1	Bradford Third	Brownish-green	45.2	38	below 5	0.1	31	0.3
2	do	Dark red N. P. A. No. 6+	45.2	39	do	below 0.1	34	0.3
3	do	Green	46.0	39	do	do	32	0.4
4	do	Green	46.0	38	do	do	30	0.3
5	do	Green	45.4	39	do	0.11	32	0.4
6	do	Green	46.5	38	do	0.15	32	0.3
7	do	Dark red N. P. A. No. 6+	44.7	39	do	below 0.1	29	0.4
8	do	Dark red N. P. A. No. 6+	45.2	39	do	do	33	0.3
9	do	Dark red N. P. A. No. 6+	44.3	44	do	do	27	0.4
10	do	Light Green	42.6	40	do	do	24	0.4
11	do	Light green	39.6	46	do	0.12	27	0.5
12	do	Light green	44.9	43	do	below 0.1	22	0.5
13	do	Green	43.6	42	do	do	27	0.5
14	do	Dark red N. P. A. No. 6+	43.6	38	do	0.11	25	0.4
15	Richburg	Brownish-green	44.1	42	do	below 0.1	30	0.4
16	Sugar Run	Light green	47.2	37	do	0.11	28	0.3
17	Bradford Second	Light green	43.2	39	do	below 0.1	26	0.5
18	do	Dark red N. P. A. No. 6+	43.4	40	do	do	27	0.4
19	Lewis Run	Light green	43.2	38	do	do	29	0.5
20	Kane	Light green	44.1	38	do	do	28	0.4
21	do	Light green	45.6	38	do	do	32	0.3

Table 51. Distillation characteristics of 21 samples of crude petroleum from Bradford field and adjacent areas.

Sample 1

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	3.1	85.5		
50 to 75	3.1	83.2		
75 to 100	6.0	71.5		
100 to 125	8.0	62.3		
125 to 150	7.0	57.2		
150 to 175	7.0	53.5		
175 to 200	4.8	50.9		
200 to 225	5.2	48.5		
225 to 250	5.8	45.8		
250 to 275	6.4	43.2		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.9	39.4	40	20
200 to 225	5.5	37.6	45	35
225 to 250	5.5	36.4	56	60
250 to 275	1.8	34.6	77	80
275 to 300	5.6	32.7	115	95
Residium..	17.5	26.6		
Loss..........	0.8			

Sample 2

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	3.6	82.2		
50 to 75	3.6	81.9		
75 to 100	5.7	70.6		
100 to 125	7.6	62.1		
125 to 150	6.1	56.7		
150 to 175	5.6	53.0		
175 to 200	5.4	50.6		
200 to 225	5.5	48.1		
225 to 250	5.7	44.9		
250 to 275	6.3	42.3		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.6	38.6	41	20
200 to 225	5.8	37.2	46	40
225 to 250	5.4	35.8	60	60
250 to 275	3.8	34.0	81	80
275 to 300	5.0	32.3	130	90
Residium..	19.7	26.6		
Loss..........	1.6			

Sample 3

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	2.3	86.2		
50 to 75	3.6	82.6		
75 to 100	4.6	72.4		
100 to 125	6.5	63.1		
125 to 150	7.0	57.4		
150 to 175	6.3	53.9		
175 to 200	4.3	51.3		
200 to 225	4.9	49.0		
225 to 250	5.4	45.6		
250 to 275	6.0	43.4		
Distillation at reduced pressure (40 mm.)				
Up to 200	6.3	38.0	42	30
200 to 225	5.3	36.2	49	55
225 to 250	4.4	34.2	62	65
250 to 275	5.7	32.3	91	82
275 to 300	5.5	29.7	157	96
Residium..	18.2	25.7		
Loss..........	3.7			

Sample 4

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	2.4	86.9		
50 to 75	3.7	81.9		
75 to 100	4.0	70.6		
100 to 125	7.1	62.9		
125 to 150	6.0	57.4		
150 to 175	5.3	54.0		
175 to 200	5.1	51.3		
200 to 225	4.9	48.8		
225 to 250	5.4	46.0		
250 to 275	5.8	43.2		
Distillation at reduced pressure (40 mm.)				
Up to 200	4.6	37.8	41	34
200 to 225	5.1	37.0	45	38
225 to 250	5.5	34.8	55	56
250 to 275	4.7	32.3	79	76
275 to 300	5.5	30.8	120	94
Residium..	20.9	25.7		
Loss..........	4.0			

Sample 5

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	2.1	86.2		
50 to 75	4.1	81.6		
75 to 100	5.0	72.7		
100 to 125	6.7	62.9		
125 to 150	5.9	57.4		
150 to 175	5.7	53.7		
175 to 200	4.7	51.3		
200 to 225	5.7	48.5		
225 to 250	5.4	45.8		
250 to 275	5.9	43.0		
Distillation at reduced pressure (40 mm.)				
Up to 200	4.1	38.0	41	30
200 to 225	4.9	37.6	45	40
225 to 250	5.7	35.0	54	65
250 to 275	4.4	31.5	75	76
275 to 300	6.4	30.4	116	90
Residium..	21.3	26.6		
Loss..........	2.0			

Sample 6

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	3.9	87.2		
50 to 75	3.0	81.3		
75 to 100	5.3	71.5		
100 to 125	7.3	62.3		
125 to 150	5.5	57.2		
150 to 175	5.3	54.0		
175 to 200	5.1	51.6		
200 to 225	5.0	48.8		
225 to 250	5.7	45.8		
250 to 275	5.5	42.8		
Distillation at reduced pressure (40 mm.)				
Up to 200	5.2	37.6	42	28
200 to 225	4.7	37.2	47	45
225 to 250	3.6	43.6	55	65
250 to 275	4.7	32.7	75	75
275 to 300	5.4	31.1	111	88
Residium..	21.1	26.1		
Loss..........	3.7			

Sample 7

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	2.9	83.2		
50 to 75	3.1			
75 to 100	5.5	72.4		
100 to 125	6.4	62.9		
125 to 150	6.0	57.4		
150 to 175	5.6	53.7		
175 to 200	5.4	50.9		
200 to 225	4.9	48.3		
225 to 250	5.3	45.4		
250 to 275	6.8	42.3		
Distillation at reduced pressure (40 mm.)				
Up to 200	2.8	39.0	40	30
200 to 225	5.5	37.6	45	40
225 to 250	5.4	36.2	55	60
250 to 275	4.5	34.2	75	75
275 to 300	5.3	32.8	115	90
Residium..	22.3	26.1		
Loss..........	2.3			

Sample 8

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F
Up to 50	3.1	83.2		
50 to 75	3.4			
75 to 100	5.1	71.5		
100 to 125	7.1	62.9		
125 to 150	5.7	57.4		
150 to 175	6.0	53.5		
175 to 200	5.6	50.4		
200 to 225	4.6	48.3		
225 to 250	5.3	45.2		
250 to 275	5.9	42.3		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.0	39.4	40	25
200 to 225	5.7	37.8	44	35
225 to 250	4.6	36.4	57	60
250 to 275	5.8	34.6	75	75
275 to 300	4.4	33.0	110	95
Residium..	22.6	27.0		
Loss..........	2.1			

Sample 9

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	3.1	83.6		
50 to 75	3.4			
75 to 100	5.3	72.4		
100 to 125	6.8	62.6		
125 to 150	6.1	56.7		
150 to 175	5.9	52.7		
175 to 200	4.5	50.4		
200 to 225	4.5	48.1		
225 to 250	5.0	44.9		
250 to 275	6.4	42.3		
Distillation at reduced pressure (40 mm.)				
Up to 200	2.8	38.6	40	20
200 to 225	5.6	37.6	45	45
225 to 250	5.0	36.0	53	60
250 to 275	4.8	34.2	72	70
275 to 300	5.9	32.8	105	90
Residium..	23.2	26.6		
Loss..........	1.7			

Sample 10

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	2.8	78.1		
50 to 75	2.1	77.2		
75 to 100	4.3	71.2		
100 to 125	6.2	62.1		
125 to 150	5.9	56.9		
150 to 175	5.3	53.2		
175 to 200	4.9	50.4		
200 to 225	4.8	48.1		
225 to 250	5.1	45.4		
250 to 275	6.6	42.3		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.1	38.1	39	20
200 to 225	5.9	37.4	44	35
225 to 250	5.3	35.8	56	55
250 to 275	5.4	34.0	74	75
275 to 300	5.9	32.3	115	90
Residium..	25.7	26.8		
Loss..........	0.7			

Sample 11

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	0.5	68.1		
50 to 75	1.1			
75 to 100	2.9			
100 to 125	5.3	61.3		
125 to 150	5.2	56.7		
150 to 175	6.0	52.7		
175 to 200	5.6	50.1		
200 to 225	5.2	47.6		
225 to 250	5.9	44.9		
250 to 275	7.5	42.1		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.7	38.4	40	20
200 to 225	5.7	37.4	45	40
225 to 250	5.4	35.6	55	50
250 to 275	5.8	34.2	75	70
275 to 300	7.0	32.3	110	85
Residium..	26.9	26.4		
Loss..........	0.3			

Sample 12

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	3.4	82.9		
50 to 75	3.1	79.1		
75 to 100	4.6	71.8		
100 to 125	6.9	63.4		
125 to 150	6.3	57.7		
150 to 175	5.7	54.2		
175 to 200	4.9	50.9		
200 to 225	4.7	48.3		
225 to 250	5.0	45.8		
250 to 275	6.3	42.8		
Distillation at reduced pressure (40 mm.)				
Up to 200	4.1	38.6	40	20
200 to 225	5.7	37.6	45	35
225 to 250	5.1	35.6	56	55
250 to 275	5.0	34.0	77	70
275 to 300	5.8	32.5	125	85
Residium..	21.5	26.1		
Loss..........	1.9			

Sample 13

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	3.2	82.9		
50 to 75	2.9	77.2		
75 to 100	4.2	71.2		
100 to 125	6.5	62.6		
125 to 150	6.4	56.9		
150 to 175	5.2	53.2		
175 to 200	4.3	50.4		
200 to 225	4.9	48.1		
225 to 250	6.1	44.9		
250 to 275	5.7	42.3		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.6	38.[illegible]	41	20
200 to 225	5.6	37.4	45	40
225 to 250	5.5	36.0	56	55
250 to 275	5.3	34.4	75	75
275 to 300	6.1	32.5	115	95
Residium.	22.9	26.3		
Loss..........	1.6			

Sample 14

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	0.8 }	80.3		
50 to 75	2.0 {			
75 to 100	4.8	71.5		
100 to 125	7.1	62.9		
125 to 150	7.7	57.9		
150 to 175	7.3	54.0		
175 to 200	6.8	51.1		
200 to 225	5.7	48.3		
225 to 250	5.6	45.4		
250 to 275	6.7	42.6		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.9	38.8	39	15
200 to 225	5.5	37.6	45	35
225 to 250	5.1	36.4	55	50
250 to 275	5.0	34.4	74	70
275 to 300	5.2	32.7	115	85
Residium..	20.2	26.1		
Loss..........	0.6			

Sample 15

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	3.2 }	83.9		
50 to 75	3.3 {			
75 to 100	4.4	69.8		
100 to 125	5.4	62.1		
125 to 150	5.9	56.7		
150 to 175	5.7	53.0		
175 to 200	5.0	50.1		
200 to 225	3.7	48.1		
225 to 250	5.7	45.4		
250 to 275	7.9	42.3		
Distillation at reduced pressure (40 mm.)				
Up to 200	4.1	38.8	40	20
200 to 225	6.3	37.2	45	40
225 to 250	5.6	35.6	56	60
250 to 275	4.7	33.8	75	75
275 to 300	6.0	32.1	115	95
Residium..	21.0	25.4		
Loss..........	2.1			

Sample 16

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	5.0	83.9		
50 to 75	4.0	83.9		
75 to 100	5.5	72.1		
100 to 125	8.0	63.4		
125 to 150	5.3	57.9		
150 to 175	5.8	54.2		
175 to 200	5.5	51.3		
200 to 225	4.6	48.8		
225 to 250	5.0	46.3		
250 to 275	6.6	43.6		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.7	39.6	39	15
200 to 225	5.7	39.0	45	35
225 to 250	5.1	37.0	52	55
250 to 275	4.9	35.4	70	70
275 to 300	5.6	33.2	110	85
Residium..	18.4	27.5		
Loss..........	1.3			

Sample 17

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	3.5	81.3		
50 to 75	3.3	79.7		
75 to 100	5.0	68.9		
100 to 125	6.9	61.5		
125 to 150	5.9	55.9		
150 to 175	5.7	52.5		
175 to 200	4.9	50.1		
200 to 225	5.4	47.4		
225 to 250	4.9	44.5		
250 to 275	6.2	41.7		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.5	37.6	40	20
200 to 225	5.1	37.0	46	35
225 to 250	5.5	35.4	55	55
250 to 275	4.7	33.6	75	75
275 to 300	6.3	31.7	120	85
Residium..	22.7	25.9		
Loss..........	0.5			

Sample 18

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	1.7 }	81.9		
50 to 75	2.7 {			
75 to 100	5.7	71.2		
100 to 125	6.8	62.6		
125 to 150	6.5	57.1		
150 to 175	5.9	53.7		
175 to 200	5.2	50.4		
200 to 225	5.0	48.1		
225 to 250	5.4	45.2		
250 to 275	6.3	42.3		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.8	38.4	40	20
200 to 225	5.4	37.6	45	35
225 to 250	4.7	35.8	56	55
250 to 275	5.1	34.0	75	75
275 to 300	5.9	32.3	120	90
Residium..	23.0	26.3		
Loss..........	0.9			

Sample 19

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	2.6	78.1		
50 to 75	3.6			
75 to 100	3.5	68.4		
100 to 125	6.5	62.1		
125 to 150	5.3	57.2		
150 to 175	5.6	53.5		
175 to 200	5.1	50.9		
200 to 225	5.1	48.3		
225 to 250	5.5	45.2		
250 to 275	6.4	42.1		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.4	38.2	40	15
200 to 225	6.2	37.4	46	35
225 to 250	5.5	35.6	57	55
250 to 275	4.9	34.0	85	75
275 to 300	6.3	32.3	125	90
Residium..	23.1	26.4		
Loss..........	1.4			

Sample 20

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	1.5	78.4		
50 to 75	2.1			
75 to 100	5.8	71.8		
100 to 125	7.1	62.9		
125 to 150	7.2	57.9		
150 to 175	6.5	54.0		
175 to 200	5.5	51.1		
200 to 225	5.7	48.8		
225 to 250	5.6	46.0		
250 to 275	7.7	43.2		
Distillation at reduced pressure (40 mm.)				
Up to 200	3.5	39.4	40	15
200 to 225	5.7	38.2	45	35
225 to 250	5.8	36.4	56	55
250 to 275	4.7	34.8	74	70
275 to 300	6.6	33.0	115	85
Residium..	18.7	26.8		
Loss..........	0.3			

Sample 21

Distillation at atmospheric pressure degrees C.	Per cent cut	Gravity A.P.I. degrees	Viscosity at 100° F.	Cloud test Deg. F.
Up to 50	2.6	83.2		
50 to 75	2.8	79.4		
75 to 100	4.9	72.1		
100 to 125	7.0	64.2		
125 to 150	7.1	58.4		
150 to 175	7.3	54.7		
175 to 200	5.7	51.8		
200 to 225	5.2	49.5		
225 to 250	6.1	46.7		
250 to 275	6.2	43.8		
Distillation at reduced pressure (40 mm.)				
Up to 200	5.0	40.0	40	20
200 to 225	4.6	38.8	45	40
225 to 250	5.3	37.0	55	55
250 to 275	4.2	35.4	75	70
275 to 300	5.0	33.8	110	85
Residium..	20.1	27.0		
Loss..........	0.9			

The U. S. Bureau of Mines has adopted the following rules for calculating the summary of fractionation and the base of crude oil.[38]

"1. The (sum) total percentage of all fractions distilling at atmospheric pressure below 100° C. (212° F.) is reported as the percentage of light gasoline. This figure approximates the yield of gasoline with a maximum boiling point of 125° C. (257° F.).

2. The (sum) total percentage of all fractions distilling at atmospheric pressure below 200° C. (392° F.) is reported as the total percentage of gasoline and naphtha if no fraction in this range has a gravity heavier than 0.825 (40° A.P.I.). This figure approximates the yield of gasoline or naphtha with a maximum boiling point of 215° C. (419° F.) (If fractions boiling below 200° C. have gravities heavier than 0.825, they are classed as gas oil.)

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[38] N. A. C. Smith and E. C. Lane. Tabulated analyses of representative crude petroleums of the United States: U. S. Bur. Mines Bull. 291, pp. 6-9, 1928.
E. C. Lane and E. L. Garton, "Base" of a crude oil: U. S. Bur. Mines, R. I. 3279, pp. 10-12, 1935.

Table 52. Summary of fractionation of 21 samples of crude petroleum from Bradford field and adjacent areas.

	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6		Sample 7	
	Per cent	Gravity A. P. I. degrees	Per cent	Gravity A. P. I. degrees	Per cent	Gravity A. P. I. degrees	Per cent	Gravity A. P. I. degrees	Per cent	Gravity A. P. I. degrees	Per cent	Gravity A. P. I. degrees	Per cent	Gravity A. P. I. degrees
Light gasoline	12.2	77.8	12.9	76.9	10.5	78.8	10.1	78.4	11.2	76.4	12.2	78.8	11.5	77.8
Total gasoline and naphtha	39.0	62.6	37.6	62.6	34.6	62.9	33.6	62.9	34.2	63.4	35.4	63.7	34.9	62.9
Kerosene distillate	17.4	45.6	17.5	44.9	16.3	45.8	16.1	45.8	17.0	45.8	16.2	45.6	17.0	44.9
Gas oil	9.3	40.2-37.0	8.3	39.2-36.8	9.5	37.4	10.0	37.0	9.6	37.2	9.3	37.0	8.4	39.4-37.0
Nonviscous lubricating distillate	11.2	37.0-33.4	10.1	36.8-33.2	10.2	36.0-31.0	10.3	35.8-31.5	10.7	36.2-30.8	10.1	36.2-31.5	10.7	37.0-33.4
Medium lubricating distillate	4.8	33.4-31.7	5.2	33.2-31.3	7.5	31.9-28.4	5.1	31.5-30.0	5.2	30.8-29.7	4.2	31.5-30.4	4.4	33.4-32.1
Residium	17.5	26.6	19.7	26.6	18.2	25.7	20.9	25.7	21.3	26.6	21.1	26.1	22.3	26.1
Carbon residue of residium	1.7		1.7		2.1		1.6		1.9		1.6		1.6	
Distillation loss	00.8		1.6		3.7		4.0		2.0		3.7		2.3	

	Sample 8		Sample 9		Sample 10		Sample 11		Sample 12		Sample 13		Sample 14	
Light gasoline	11.6	77.8	11.8	78.4	9.2	74.8	4.5	68.1	11.1	77.2	10.3	76.3	7.6	74.8
Total gasoline and naphtha	36.0	62.9	35.1	63.1	31.5	61.0	26.6	57.2	34.9	62.9	32.7	62.3	36.5	60.0
Kerosene distillate	15.8	45.2	15.9	44.7	16.5	44.9	18.6	44.5	16.0	45.4	16.7	44.9	18.0	45.2
Gas oil	8.3	40.0-37.2	9.2	39.0-36.6	9.0	39.2-36.6	9.4	38.8-36.6	9.4	39.0-36.8	9.2	38.0	9.4	39.2-37.0
Nonviscous lubricating distillate	11.6	37.2-33.4	11.2	36.6-33.0	11.6	36.6-32.8	12.9	36.6-32.8	10.6	36.8-33.2	11.8	36.8-33.2	10.9	37.0-33.2
Medium lubricating distillate	3.6	33.4-32.5	3.7	33.0-32.1	5.0	32.8-31.3	5.3	32.8-31.3	5.7	33.2-31.7	5.1	33.2-31.5	4.4	33.2-31.9
Residium	22.6	27.0	23.2	26.6	25.7	26.8	26.9	26.4	21.5	26.1	22.9	26.3	20.2	26.1
Carbon residue of residium	1.5		1.8		1.7		2.0		2.1		2.1		2.2	
Distillation loss	2.1		1.7		0.7		00.3		1.9		1.6		0.6	

	Sample 15		Sample 16		Sample 17		Sample 18		Sample 19		Sample 20		Sample 21	
Light gasoline	10.9	77.8	14.5	79.4	11.8	75.4	10.1	75.7	9.7	74.5	9.4	74.2	10.3	76.9
Total gasoline and naphtha	32.9	62.3	39.1	64.8	35.2	61.8	34.5	61.5	32.2	61.3	35.7	61.0	37.4	62.3
Kerosene distillate	17.3	44.5	16.2	45.8	16.5	44.3	16.7	44.9	17.0	44.9	19.0	45.6	17.5	46.5
Gas oil	10.1	39.4-36.4	10.6	38.8	8.5	37.8-36.4	8.9	38.8-36.8	8.7	38.6-36.8	9.0	39.8-37.4	10.0	39.2
Nonviscous lubricating distillate	11.6	36.4-32.8	10.4	37.6-33.8	11.1	36.4-32.5	10.7	36.8-33.0	11.0	36.8-33.4	12.0	37.4-33.6	10.4	37.8-34.2
Medium lubricating distillate	5.0	32.8-31.1	4.0	33.8-32.3	5.5	32.5-30.6	5.3	33.0-31.3	6.6	33.4-31.3	5.3	33.6-32.1	3.7	34.2-33.0
Residium	21.0	25.4	18.4	27.5	22.7	25.9	23.0	26.3	23.1	26.4	18.7	26.8	20.1	27.0
Carbon residue of residium	2.0		1.7		2.0		1.8		2.1		2.1		1.6	
Distillation loss	2.1		1.3		0.5		0.9		1.4		0.3		0.9	

3. The (sum) total percentage of all fractions distilling at atmospheric pressure above 200° C. (392° F.) but below 275° C. (527° F.) that have gravities of 0.825 (40° A.P.I.) or lighter is reported as kerosene distillate.

4. The (sum) total percentage of all fractions distilling at atmospheric pressure below 275° C. (527° F.) that have gravities heavier than 0.825 (40° A.P.I.) plus all vacuum distillate with a viscosity less than 50 seconds (Saybolt Universal at 100° F.) is reported as gas oil.

5. Lubricating distillates are classified as follows: Distillate with a viscosity range (Saybolt Universal at 100° F.) between 50 and 100 seconds is reported as non-viscous lubricating distillate. Distillate with viscosity between 100 and 200 seconds is reported as medium lubricating distillate. Distillate with viscosity above 200 seconds is reported as viscous lubricating distillate. The percentages of the lubricating distillates are calculated by plotting the gravities and viscosities of the individual fractions separately against "volume sum percentages" and noting where the 50-second, 100-second and 200-second points on the viscosity curve intercept the "volume sum percentage" coordinate. The gravities corresponding to these intercepts give the gravity ranges of the distillates."

The base of a crude oil is determined as follows:

"1. Note the A. P. I. gravity of "key fraction No. 1," the fraction distilling between 250° and 275° C. (482° and 527° F.) at atmospheric pressure.

2. Note the A. P. I. gravity of "key fraction No. 2," the fraction distilling between 275° and 300° C. (527° and 572° F.) at 40 mm. absolute pressure.

If the gravity of key fraction No. 1 is 40.0° A. P. I. or lighter, the lower-boiling fractions of the oil are paraffinic in character; if it is 33.0° A. P. I. or heavier, they are naphthenic; and if it is between 33.0° and 40.0° (33.1° to 39.9° A. P. I., inclusive) they are intermediate.

Similarly, if the gravity of key fraction No. 2 is 30.0° A. P. I. or lighter, the higher-boiling fractions of the oil are paraffinic in character. They are naphthenic if key fraction No. 2 is 20.0° A. P. I. or heavier and intermediate if the key fraction is between 20 and 30 (20.1° to 29.9°, inclusive). Thus, there are nine possible classes of crude oils:

1. Paraffin base: Distillates paraffinic throughout.
2. Paraffin - intermediate base: Light fractions paraffinic; heavy fractions intermediate.
3. Intermediate - paraffin base: Light fractions, intermediate; heavy fractions, paraffinic.
4. Intermediate base: Distillates, intermediate throughout.
5. Intermediate - naphthene base: Light fractions, intermediate; heavy fractions, naphthenic.
6. Naphthene - intermediate base: Light fractions, naphthenic; heavy fractions, intermediate.
7. Naphthene base: Distillates naphthenic throughout.
8. Paraffin - naphthene base: Light fractions, paraffinic; heavy fractions, naphthenic.
9. Napthene - paraffin base: Light fractions, naphthenic; heavy fractions, paraffinic.

To determine the presence or absence of wax, note the "cloud point" of key fraction No. 2, the fraction distilling between 275° and 300° C. (527° and 572° F.) at 40 mm. absolute pressure. If this is below 5° F., it indicates that wax is absent, but if it is above 5° F., it indicates that wax is present."

An inspection of the 21 analyses shows definitely that all of these crudes have a paraffin base and are wax-bearing.

The first ten samples represent crude oil from the Bradford Third sand from different parts of the Bradford pool. Sample 1 came from a well in the extreme northeast, on the edge of the area occupied by the gas "pay" on the Knapp Creek dome. Sample 2 came from the north-central part; samples 3 to 6, inclusive, from the northern part of the northwestern lobe within a radius of 750 feet of one another; sample 7, from the central part of the same lobe; sample 8, from the north-central part of the southeastern lobe; sample 9, from the tip of the eastern prong of that lobe, and sample 10, from the tip of the western prong near the edge of the pool and close to the oil-salt water contact.

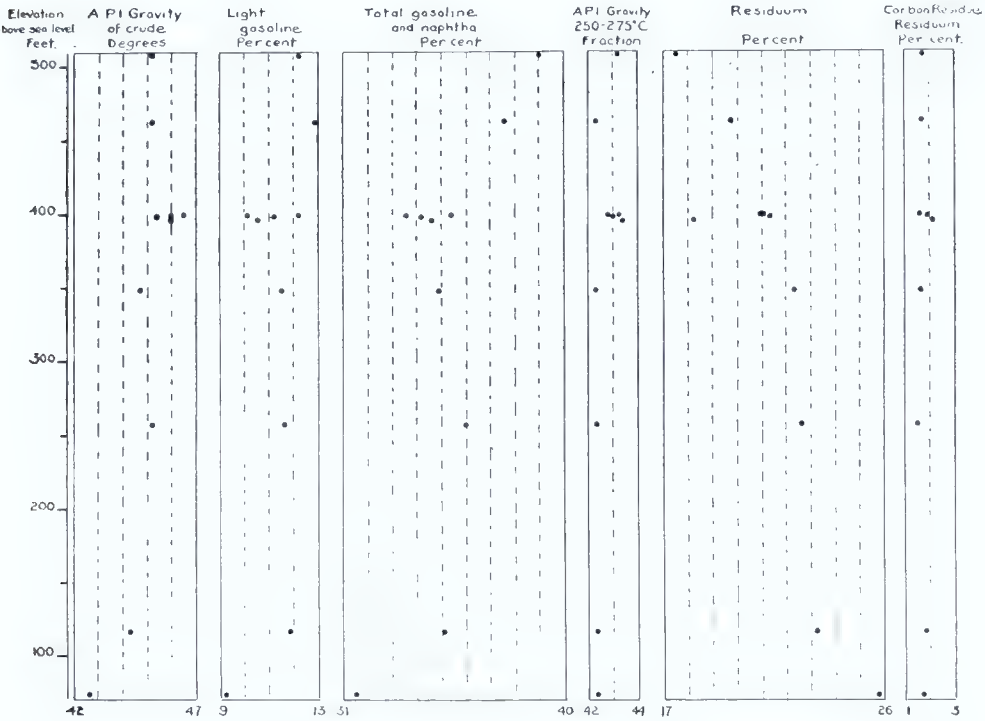

FIGURE 29. **Relation of variations in 10 samples of crude petroleum from Bradford pool to position on structure.**

In order to determine to what extent position with respect to the structure might cause the variations shown by the samples, the A. P. I. gravity of the crude, the percent light gasoline content, the percent total gasoline and naphtha, the A. P. I. gravity of the 250-275° C. fraction, the percent residium, and the percent carbon residue of the residium have been plotted in Figure 29 with respect to elevation above sea level of the sand where the sample was collected. The diagram shows that the variations in A. P. I. gravity and light gasoline content in the crude now produced have little or no relation to position on the structure, with the possible exception of one sample lowest on the structure and adjacent to the oil-salt water contact. In the case of the total gasoline and naphtha content, the two samples highest on the structure show the highest percent and the one sample lowest on the structure, the lowest—the variations of the intermediate samples being irregular. The A. P. I. gravities of the 250-275° C. fraction show no variations that can be attributed to position on the structure. The percent of residium shows the best alignment with respect to position on structure. Only one sample out of the ten failed to show an increase in residium content with descent on structure. The carbon residue of the residium shows no relation to structure.

In making the above comparisons, it must be remembered that the Bradford pool, when the samples were taken, had practically reached the economic limit by natural methods of production and that the remaining oil had undoubtedly undergone some changes, such as a loss of some of its more volatile constituents during the more than half a century that have elapsed since its discovery. The diagram of Figure 29 seems to suggest rather definitely that the oil on the highest part of the structure originally had a somewhat higher A. P. I. gravity and a higher content of the lighter fractions than that on the lower parts of the structure.

Samples 11 to 15 represent crudes from the Bradford Third sand from nearby pools, including the Richburg of Allegany County, New York, that are not continuous with the Bradford pool. With the exception of No. 11, the samples show no appreciable variation from the ten samples collected in the Bradford pool. Their A. P. I. gravities are a trifle lower. Sample 11 shows a noticeably lower gravity. It comes from one of two very small pools in the otherwise non-productive area of thin sand which separates the two lobes of the Bradford pool. Considerable salt water is produced with the oil. It resembles sample 10 more closely than any of the others but has a still lower gravity.

Samples 16 to 20 are crudes obtained from the sands above and below the Bradford Third in the Bradford district and are representative of the oils occurring in a stratigraphic interval of about 750 feet. These analyses reveal no variations sufficiently marked to distinguish the oil of one horizon from that of another or from the Bradford Third.

WATER IN THE OIL AND GAS SANDS

The subsurface waters in the Bradford field may be divided into three types on the basis of their origin. The first type is the water in the oil and gas sands, which, in considerable part at least, probably represents sea water entrapped in the sediments when they were laid down. This type is usually referred to as connate water. The second type is the relatively shallow ground water in the alluvial deposits and in the uppermost part of the bedrock. This is meteoric or rain water that has soaked into the ground. In the Bradford district it is confined almost entirely to the uppermost 300 to 500 feet of strata regardless of the horizon at which a particular well starts. The third type is the flood water that is pumped with the oil in water-flooding operations. It is a mixture of the first two types.

CONNATE WATER

Lane[39] originally applied the term connate to water entrapped in sediments when they were laid down. He made no distinction between fresh and marine types. Owing to the practical impossibility in most instances of distinguishing fresh connate from ordinary surface waters, the term has come to be more or less restricted to the marine type. Water is a very mobile substance. Connate water may, therefore, have wandered not only widely in the bed in which it was originally included, but it may have migrated from one bed to another and been joined by waters from other beds and even from the surface. Water is also very active chemically. The amount and composition of the constituents in solution in a connate water have undergone marked changes since the water was enclosed in the sediments. The connate water in a sand body, therefore, does not have the concentration and composition of the original sea water nor is it necessarily the water that was originally included between the grains of that particular sand body. It can be regarded simply as a fossil sea water.

Occurrence

With the exception of wells near the edges of the Bradford pool, the Bradford Third sand has yielded little or no salt water from wells not affected by artificial water floods. Some of the older operators report, however, that early in the life of the pool a little water was produced from wells in areas now regarded as dry.[40] Although the Bradford pool is generally considered to be a dry-sand field, the term "dry" is only relative, meaning that no measurable quantities of water are produced with the oil. It does not necessarily mean that the sand is dry in a chemical sense.

There is a fairly definite oil-salt water contact along the western, southern and southeastern margins of the Bradford pool, but not at any definite elevation. In the otherwise non-productive area on the southeastern flank of the Bradford anticline, where some of the steepest dips in the field occur, between the two lobes of the Bradford pool, considerable salt water is produced with a little oil from the two small pools along Minard Run (Plate E). The sand here is thin, as shown by core 15. Numerous wells have been drilled through the Bradford Third at the southern edge of the borough of Lewis Run to the Lewis Run sand. In many of these wells salt water and only a showing of oil were found in a thin sand interstratified with numerous shale layers occurring at the Bradford Third horizon. Salt water has also been reported from a sand that is thought to represent the Bradford Third horizon along Allegheny River north of the Bradford pool. Several wells drilled in recent years along the Simpson anticline in the non-productive area separating the Guffey from the Bradford pool have also met salt water with only a little oil in the Bradford Third sand. The sand also contains salt water along the southern margins of the Guffey pool.

In a well drilled during the spring of 1926 by the Berwald and Odell Oil Company in the western part of Warrant 3433, Lafayette Township, about half a mile west of the edge of the Bradford pool at the southwest tip of the southeast lobe, salt water in the Bradford Third sand was under sufficient head to rise 1,200 feet in the hole. It entered the well at the rate of only 30 barrels per day, however, and was accompanied by a little gas and oil. The water had a density of 1.1, which would indicate a reservoir pressure of 570 pounds per square inch at this locality. Only half a mile away in the Bradford pool, however, on an edge property, where pressure has been reduced almost to atmospheric, there has been an increase in the quantity of salt water produced in wells that have been pumping for more than ten years. This no doubt is due to the low porosity and permeability of the sand and the lenticular character of the individual sand layers that make up the sandy body.

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[39] A. C. Lane, Mine waters and their field assay: Bull. Geol. Soc. America, vol. 19, p. 502, 1909.

[40] Paul D. Torrey, Oil-field waters of the Bradford pool: Am. Inst. Min. Eng., Tech. Pub. 38, p. 2, 1927.

This condition apparently prevails throughout much of the southern part of the Bradford district. South of the Bradford pool there is considerable area in which the Bradford Third sand contains salt water. Usually a little oil and gas are associated with it. The water is under pressure in parts of the area at least or it would not rise in the wells. Obviously it is not under an artesian head because this area is on the down dip side of an oil pool in which the pressure has been reduced almost to atmospheric. The sand continues to descend to the south and does not crop out in that direction. The reservoir pressure on the water in this area, as in the west side of the East Texas field,[41] apparently is due to the expansive power of the salt water itself and the small amounts of oil and gas associated with it. Around the margins of the Bradford pool, however, the porosity and permeability of the sand are so low and the individual sand layers are so interbedded with shale and lenticular in character that no very large volume of water is available and hence no noticeable edge water encroachment has taken place as the oil has been withdrawn from the pool. What little salt water has entered has come in so slowly that it has been removed by pumping.

In the Bradford pool enough salt water in the sands above the Bradford Third to necessitate setting an extra string of casing is practically never encountered. On the extreme northern edge of the pool in the Nichol Run and Chipmunk districts, the Bradford First sand sometimes contains sufficient salt water to make it necessary to case this off before drilling deeper. West of the Bradford pool much salt water is frequently found in the Bradford Second sand. Some salt water occurs in both the Bradford Third and Kane sands in the Ormsby pool.

Composition

Water analyses are now commonly stated in the ionic form in parts per million, the reason being that the water analyst cannot determine with certainty what compounds have been dissolved, nor can he ascertain by the ordinary methods of analysis what compounds, if any, exist in the solution. His work is limited mostly to the determination of the parts of compounds, known as ions or radicles, that are present in the water.

The statement of a water analysis in ionic form in parts per million shows numerically the relative proportion of the several radicles by weight and, therefore, is not a numerical representation of the water as a chemical agent. For purposes of comparison, it is more convenient to have a statement of the analysis in terms of reacting values, which show numerically the relative proportions of the radicles in terms of reaction capacity. To convert an analysis from the ionic form into one of reacting values, Stabler[42] has suggested that the weight of each radicle be multiplied by a "reaction coefficient" which represents its valence divided by its atomic or molecular weight. In the conversion of the water analyses included in this report, the following reaction coefficients were used:

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[41] Ralph J. Schilthuis and William Hurst, Variations in reservoir pressure in the East Texas field: Trans. Am. Inst. Min. Eng., vol. 114, p. 168, 1935.

Positive radicles		**Negative radicles**	
Calcium (Ca)......	.0499	Bicarbonate (HCO_3)	.0164
Magnesium (Mg) ..	.0822	Sulphate (SO_4).....	.0208
Sodium (Na).......	.0435	Chloride (Cl)	.0282
Potassium (K)......	.0256	Bromide (Br)......	.0125

The reacting value of a radicle is indicated by prefixing the letter r to its symbol. If all the constituents in solution in a water have been determined, the sum of the reacting values of the positive radicles should be the same as that of the negative radicles.

In this report the reacting values have been stated both in terms of milligrams per liter and on a percentage basis. The latter further facilitates comparison. All comparisons have been made on the basis of reacting values.

Analyses of four samples of connate water from the Bradford Third sand, representing the waters along the western, southwestern, southern and eastern margins of the Bradford pool, are given in Table 53. An analysis of a connate water from the Kane sand in the Kane pool and the mean of 77 analyses of ocean water are included for comparison.

Table 53. Analyses of connate water from Bradford Third and Kane sands and ocean water.

Sample number	1	2	3	4	5	6
Constituents in parts per million						
Radicles:						
Iron (Fe)	119				38	
Calcium (Ca)	16,860	13,260	15,300	12,086	14,370	420
Magnesium (Mg)	2,530	1,940	1,664	2,240	2,118	1,300
Sodium (Na)	38,900	31,950	29,980	33,810	33,800	10,710
Potassium (K)	272	650			203	390
Carbonate (CO_3)	0	0	0	0	0	70
Bicarbonate (HCO_3)	0	0	0	0	0	
Sulphate (SO_4)	565	730	822	840	1	2,700
Chloride Cl)	97,000	77,340	76,300	79,540	84,000	19,350
Bromide (Br)	540	320			36	60
Iodide (I)	11	10			9	
Total dissolved solids	158,300	130,640			137,300	
Reacting values in milligrams per liter						
r Ca	841.6	661.9	763.6	603.0	717.2	21.0
r Mg	208.0	159.5	136.8	184.2	174.2	106.9
r Na	1,691.3	1,389.1	1,303.5	1,470.0	1,469.8	465.9
r K	7.0	16.6			5.2	10.0
r SO_4	11.8	15.2	17.2	17.4		56.2
r CI	2,735.7	2,181.6	2,151.9	2,243.3	2,369.1	545.7
r Br	6.8	4.0				.8
r I	0.1	0.1				
Concentration value	5,502.3	4,428.0	4,373.1	4,517.9	4,735.5	1,206.5
Reacting values in percent						
r Ca	15.3	14.9	17.3	13.4	15.2	1.7
r Mg	3.8	3.6	3.1	4.1	3.7	8.9
r Na (include r K)	30.9	31.5	29.6	32.5	31.1	39.4
r SO_4	0.2	0.4	0.4	0.4		4.8
r CI (includes r Br and r I)	49.8	49.6	49.6	49.6	50.0	45.2

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[42] Herman Stabler, The industrial application of water analyses: U. S. Geol. Survey, Water Supply Paper 274, pp. 167-168, 1911.

SOURCE OF CONNATE WATER SAMPLES LISTED IN TABLE 53

1. Bradford Third sand from Berwald and Odell Oil Company's No. 1 well, ½ mile west of extreme western edge of tip of southeast lobe of the Bradford pool, Lafayette Township, McKean County. Elevation of top of Bradford Third sand, 49 feet above sea level. Sample collected by Chas. R. Fettke, summer 1926. Analyzed by U. S. Geological Survey.

2. Bradford Third sand from Associated Producers Company's Stover No. 23 well, near southern edge of southeast lobe of Bradford pool, in the vicinity of Bingham, Lafayette Township, McKean County. Elevation of top of Bradford Third sand, 157 feet above sea level. Sample collected by Paul D. Torrey, May 4, 1926. Analyzed by U. S. Geological Survey.

3. Bradford Third sand from Bovaird and Enright's Songbird No. 13 well, on northwest flank of northwest lobe of Bradford pool, Bradford Township, McKean County. Elevation of top of Bradford Third sand, 320 feet above sea level Sample collected by property foreman, August 4, 1926. Analyzed by C. R. Wright.

4. Bradford Third sand from D. T. Andrus's Duke and Harris No. 7 well, near southeast edge of Bradford pool, at north end of southeast lobe, Otto Township, McKean County. Elevation of top of Bradford Third sand, 347 feet above sea level. Sample collected by Paul D. Torrey, Sept. 30, 1926. Analyzed by C. R. Wright.

5. Kane sand from Sloan and Zook Company's Indian No. 12 well, in Kane pool, Highland Township, Elk County. Approximate depth top of Kane sand, 2,370 feet. Sample collected by Chas. R. Fettke, August 28, 1930. Analyzed by U. S. Geological Survey.

6. Mean of 77 analyses of ocean water from many localities, collected by the Challenger expedition, W. Dittmar, analyst. Challenger Rept., Physics and Chemistry, vol. 1, page 203, 1884.

The four samples of connate water from the Bradford Third sand and the sample from the Kane sand show but little variation in concentration and composition of dissolved salts, the Kane sample being almost identical with No. 1 from the Bradford Third.

When compared with ocean waters, a considerable difference in both concentration and composition is evident. Most geologists probably will agree that the composition of the ocean waters when these Upper Devonian sediments were laid down was not essentially different from that of today. The question then arises, What has brought about the changes in concentration and composition exhibited by these waters if they are essentially of connate origin?

Extensive upward migrations of waters originally included interstitially in the sediments, must have occurred as the latter underwent compaction and induration. Water from lower beds escaped up through and along higher beds. Abundant opportunities occurred for the waters to react with the mineral constituents of the rocks. Increase of pressure and temperature with depth of burial also increased the solvent power of the waters.

In the stage of compaction and induration reached by the Upper Devonian strata of the Bradford district, the connate water now present in the sandstone reservoirs is only a very small fraction of the water that was included in these sediments when deposited.

In order to get a concentration of salts equivalent to that of sample 1, ocean water would have to be evaporated down to 22 percent of its original volume. Torrey[43] strongly favors the theory of Mills and Wells that the concentration of the connate water has been brought about largely by progressive evaporation of the water into moving and expanding gas migrating through the sediments. Dorsey,[44] on the other hand, thinks that the concentration is due to the fact that increases of pressure and temperature greatly increase the ability of the water to dissolve salts, thereby enhancing its leaching powers.[44] The salts in the connate waters of the Bradford Third sand contain nearly 50 percent of chlorine, which is even greater than the amount in the salts derived from ocean water. If the concentration was brought about by leaching, the source of the chlorine has to be explained. Chlorine is only a very minor constituent in common rock-forming minerals; most of them do not contain it at all. If the concentration was due to leaching, therefore, the presence of saline salts, derived from oceanic or similar waters, in the strata with which the waters came in contact would have to be postulated. It does not seem likely that at the time of deposition, the sediments in question were ever exposed to the air long enough to permit sufficient desiccation to cause the deposition of chlorides from oceanic waters in their interstices. Desiccation of enclosed oceanic waters and deposition of salts in the interstices of the sediments after burial, which could later be leached out by migrating waters, brings one back to the original problem.

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[43] Paul D. Torrey Oil-field waters of the Bradford pool: Am. Inst. Min. Eng., Tech. Paper 38, p. 11, 1927.

R. Van A. Mills and Roger C. Wells, The evaporation and concentration of waters associated with petroleum and natural gas: U. S. Geol. Survey, Bull. 693, pp. 67-68, 1919.

The salts in the connate water of the Bradford Third sand differ rather markedly in chemical composition from those in ocean water in several respects. In ocean water the magnesium to calcium ratio is 5:1, whereas in sample 1 this ratio is only 1:4. Mills and Wells[45] have discussed at considerable length various ways in which this change may have been brought about. Magnesium in solution may have been exchanged in part for calcium in calcite, forming dolomite. With moderate rise in temperature there is a possibility that magnesium chloride may have been hydrolyzed—$MgCl_2 + 2H_2O = Mg(OH)_2 + 2HCl$. The hydrochloric acid formed would react with carbonates in the sediments to form carbon dioxide, which would precipitate the magnesium as a carbonate. Magnesium may also have been lost from solution by replacing calcium in silicates. It is interesting to note in this connection that the chemical analysis of a sample of Bradford Third sandstone in which only traces of carbonate occurred, contained 0.42 percent magnesia and only 0.07 lime.

There is a noticeable increase in the ratio of calcium to chlorine in the connate waters as compared to ocean water, even after the substitution of calcium for magnesium in the latter has been taken into consideration. This suggests that, as the waters became more concentrated with respect to sodium chloride, a base exchange of calcium for sodium occurred similar to that which occurs in the zeolite process of water softening. In this process hard waters are filtered through beds of artificial zeolites, which consist of complex alkali aluminosilicates. The calcium and magnesium are deposited, replacing equivalent amounts of sodium which go into solution. The zeolites are regenerated by passing strong solutions of sodium chloride through them, the magnesium and calcium in the bed being thereby carried out as magnesium and calcium chlorides, and the sodium zeolite is renewed. The reaction is reversible, going in one direction or the other in accordance with the concentration of calcium and magnesium or of sodium in the solution.

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[44] Geo. Edwin Dorsey, Preservation of oil during erosion of reservoir rocks: Bull. Am. Asso. Petroleum Geologists, vol. 17, p. 840, 1933.
[45] R. Van A. Mills and Roger C. Wells, Idem, pp. 70-76, 1919.

The ratio of potassium to sodium in the connate waters is considerably smaller than in ocean water, being 1:241 in sample 1, 1:84 in sample 2, and 1:282 in sample 5 as compared to 1:46 in ocean water. Sullivan[46] has discussed the experimental evidence indicating that potassium may be removed from saline waters through the selective action of hydrated aluminosilicates such as those that occur in clay and shales. The replacement of sodium in silicates by the potassium of a dissolved salt takes place far more readily than the reverse action. A similar relation, although perhaps not quite so marked, exists between magnesium and calcium silicates.

The low sulphate content of the connate waters is another outstanding characteristic. The ratio of sulphate to chloride in sample 1 is 1:232; in sample 2, 1:143; in sample 3, 1:125; in sample 4, 1:129; and in sample 5, practically 0, as compared to 1:10 in ocean water. Torrey [47] has attributed this low sulphate content to precipitation of calcium sulphate in the sand during the concentration of the water. In order to get a concentration of salts equivalent to that of sample 1, ocean water would have to be evaporated down to 22 percent of its original volume. According to the experiments of Usiglio, however, ocean water has to be evaporated to 19 percent of its original volume before any precipitation of calcium sulphate occurs and it is not complete until the volume has been reduced to 3 percent. Some sulphate still remains in solution after all the calcium has been precipitated.[48] While locally, therefore, it is quite probable that concentration proceeded to the stage where some calcium sulphate was deposited in the sand, particularly since the increase in calcium chloride content of the waters would decrease the solubility of the calcium sulphate, it does not seem possible to assign the entire loss of sulphate to precipitation alone.

Rogers,[49] in studying the oil-field waters in the San Joaquin Valley of California, came to the conclusion that the sulphate was probably reduced to a sulphide or hydrogen sulphide by certain of the constituents present in the oil or gas. In this connection, attention should be called to the fact that occasional clusters of minute pyrite crystals, clearly of secondary origin, were observed in both thin and polished sections of Bradford Third sand and that pyrite is the predominating constituent in the heavy mineral concentrate separated from the sand with bromoform. There is still some question, however, as to whether inanimate organic matter is capable of reducing sulphates in subsurface waters.[50] As will be pointed out in the section on flood waters, the sulphur remains in part at least in the sand in some form because it makes its appearance again as a sulphate in the flood waters.

No carbonates or bicarbonates have thus far been recognized in connate waters from the Bradford Third sand.

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[46] Eugene C. Sullivan, The interaction between minerals and water solutions: U. S. Geol. Survey Bull. 312, p. 22, 1907.

[47] Paul D. Torrey, op.cit., p. 13, 1927.

[48] W. H. Twenhofel, Treatise on sedimentation, second edition, p. 465, Baltimore, 1932.

[49] G. Sherburne Rogers, Chemical relations of the oil-field waters in the San Joaquin Valley, California; U. S. Geol. Survey Bull. 653, p. 44, 1917.

[50] Roy L. Ginter, Sulphate reduction in deep subsurface waters, Problems of Petroleum Geology: Am. Assoc. Petroleum Geologists, pp. 907-925, 1934.
C. W. Washburne and F. H. Lahee, Oil-field waters, idem, pp. 836-837.

FLOOD WATER

It has been pointed out that, although noticable quantities of water have not been produced with the oil in large parts of the Bradford pool, this does not necessarily mean that the sand is entirely free from moisture. Water adheres to the pore walls of a sandstone more tenaciously than does oil, and a sand may, therefore, possess an appreciable moisture content and yet not yield any water with the oil.

The water at present introduced into the sand in flooding operations is shallow ground water. This water in passing through the sand not only drives oil ahead of it, but it also picks up the small amounts of connate water clinging to the walls of the pores. While the concentration of the flood water, therefore, depends largely upon the extent to which the one type has been diluted by the other, its composition indicates that more profound chemical changes have occurred than are involved in the mere mingling of the two types of water.

Composition

During the spring and summer of 1926, Paul D. Torrey made a study of the character of the flood waters of the Bradford field, in connection with which he collected more than 100 samples. This work was sponsored jointly by the Northwestern Pennsylvania Oil Producers Association and the United States Geological Survey. The samples were analyzed by W. D. Collins, C. S. Howard, S. K. Love and E. A. Swedenborg of the Water Resources Branch of the latter organization. Torrey[51] has discussed the more salient features brought out by these studies in a paper on the oil-field waters of the Bradford pool.

On account of the large number of analyses involved in Torrey's work, the alkalies were not determined directly in the samples of flood water, but their amounts were calculated on the assumption that the difference between the sum of the reacting values of the carbonate, bicarbonate, sulphate and chloride radicles and the sum of the reacting values of the calcium and magnesium radicles, represented the reacting value of the sodium present. Comparison of these analyses with those of seven samples of flood water collected later by the writer, in which all the essential constituents were determined, shows that no appreciable error resulted by making this assumption.

The U. S. Geological Survey not only made twelve complete analyses of waters from the Bradford district for the writer, but also turned over to him all the analyses made of Torrey's samples for use in preparation of the present report.

When a well first starts to show a slight pick-up in oil production owing to an approaching water drive, a little water is usually produced with the oil. Analyses showing the nature of this water have been assembled in Table 54. Samples 7, 8, 9 and 10 are of this type. Sample 1 of the connate water has been included for comparison. Samples 10 and 11, taken less than one month apart, show how rapidly the concentration changes as the flood proceeds. When sample 10 was taken, the well had produced 221 barrels of oil and only 6 barrels of water. In the interval which elapsed between the taking of samples 10 and 11, 156 more barrels of oil were produced and 20 barrels of water.

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[51] Paul D. Torrey, Oil field waters of the Bradford pool: Am. Inst. Min. Eng., Tech. Publication 38, 1927.

Table 54. Analyses of connate and first flood water from Bradford Third sand.

Sample number	1	7	8	9	10	11
Date sampled	Summer 1926	9-5-26	4-22-26	4-27-26	4-22-26	5-30-26
Average daily oil production, barrels		.14	.30	.80	2.93	4.48
Average daily water production, barrels		.02	.16	.01	.26	.60
Constituents in parts per million						
Radicles:						
Calcium (Ca)	16,860	10,410	8,422	9,540	7,356	2,627
Magnesium (Mg)	2,530	1,755	1,460	1,565	1,215	503
Sodium (Na) calculated	39,172	28,750	21,510	25,570	20,270	7,676
Carbonate (CO_3)	0	0	0	0	0	0
Bicarbonate (HCO_3)	0	34	14	38	37	40
Sulphate (SO_4)	565	301	15	1,081	825	620
Chloride (Cl)	97,551	67,640	52,280	60,040	47,170	17,470
Sum	156,678	108,890	83,701	97,834	76,873	28,936
Reacting values milligrams per liter						
r Ca	841.6	519.6	420.4	476.2	367.2	131.2
r Mg	208.0	144.3	120.0	128.7	99.9	41.4
r Na	1,698.3	1,250.8	935.1	1,111.9	881.5	333.7
r HCO_3		.6	.2	.7	.6	.7
r SO_4	11.8	6.3	.3	22.5	17.2	12.9
r Cl	2,742.6	1,907.9	1,475.0	1,693.6	1,330.8	492.7
Concentration value	5,502.3	3,829.5	2,951.0	3,433.6	2,697.2	1,012.6
Reacting values in percent						
r Ca	15.3	13.6	14.2	13.8	13.6	13.0
r Mg	3.8	3.8	4.1	3.8	3.7	4.1
r Na	30.9	32.6	31.7	32.4	32.7	32.9
r HCO_3						
r SO_4	.2	.2		.7	.6	1.3
r Cl	49.8	49.8	50.0	49.3	49.4	48.7

SOURCE OF SAMPLES OF FLOOD WATER LISTED IN TABLE 55

7. Petroleum Reclamation Company's Hawkins-Clark No. 3, in northern part of northwest lobe of Bradford pool.

8. Petroleum Reclamation Company's Hawkins-Bryner No. 12, same locality as 7.

9. Petroleum Reclamation Company's Hawkins-Bryner No. 27, same locality as 7.

10. Kendall Refining Company's Neath-Bolton No. 63 well, in north-central part of Bradford pool.

11. Neath-Bolton No. 63, later date.

Sample 7 collected by H. M. Ryder; 8, 9, 10 and 11 by Paul D. Torrey; analyses made by U. S. Geological Survey.

It will be noted that the first flood water is highly concentrated, although somewhat less than the connate water. The only important difference in composition is a small amount of the bicarbonate radicle in the flood water. As far as is known, the connate water contains no bicarbonate. Its appearance in the water, therefore, as Torrey has pointed out, indicates either that there is a leak in the casing or that flood water is entering the well.

The writer is of the opinion that the first flood water consists in considerable part of connate water very similar in composition to that around the margins of the pool, which is adhering to the pore walls of the sandstone and is swept along by the advancing flood water. In this respect, he differs from Torrey, who believes that the sandstone is essentially free from water and the salts precipitated in its pores are taken into solution by the flood water as it advances through the sand.

It is hard to conceive that salts such as calcium, magnesium and sodium chloride could have been precipitated in the sand in just the right proportions so that later flood waters in passing through the sand would take them into solution in almost the same proportions in which they are now present in the connate water around the margins of the pool.

In order to have a further comparison, the theoretical composition of a water of similar concentration to that of sample 8 was calculated on the assumption that it was a mixture of connate water similar to that of sample 1 and a shallow ground water such as was used for flooding purposes on the particular property on which the well was located. It was found that 53 parts of the connate water and 47 parts of the shallow ground water would give the proper concentration. In such a mixture the composition in terms of reacting values in percent as compared to the actual values would be as follows:

	Composition	
	Theoretical	Actual
r Ca	15.3	14.2
r Mg	3.8	4.1
r Na	30.9	31.7
r HCO_3	.1	.01—
r SO_4	.2	.01+
r Cl	49.7	49.98

The similarity is so striking that it can hardly be considered accidental.

Seven analyses of flood waters in which all the essential constituents were determined are shown in Table 55. The samples came from wells in the south and east-central parts of the Bradford pool that were at different stages in their life cycles. The average daily production is for the month in which the sample was taken and the total production, up to the time the sample was collected.

Table 55. *Analyses of flood waters from Bradford Third sand*

Sample number	12	13	14	15	16	17	18	19
Date sampled	8-14-30	8-28-30	8-28-30	8-14-30	8-29-30	8-29-30	8-29-30	9-13-26
Average daily oil production—barrels	1.90	2.28			2.58	5.59	.87	.73
Average daily water production—barrels	4.56	2.58			4.13	8.00	17.35	15.62
Total oil production—barrels		308			3310	4145		
Total water production—barrels		202			3040	2990		
Constituents in parts per million								
Radicles:								
Iron (Fe)	5.5	24.6	10.2	8.3	5.5	.6	.9	
Calcium (Ca)	1497	1302	934	584	645	474	282	147
Magnesium (Mg)	262	356	225	115	118	87	49	20
Sodium (Na)	4230	4380	4240	2018	3010	2388	1318	501 (calc.)
Potassium (K)	26	27	24	6.4	8.4	7.2	8.4	
Carbonate (CO_3)	0	0	0	0	0	0	0	0
Bicarbonate (HCO_3)	161	465	176	458	173	186	197	329
Sulphate (SO_4)	38	1096	389	237	756	832	570	230
Chloride (Cl)	9840	9050	8500	4060	5,540	4,080	2,152	730
Bromide (Br)	10	less than 5	5	15	10	20	15	
Iodide (I)	3	less than 1	1	1	2	1	1	
Total dissolved solids	16,230	16,550	14,540	7,360	10,350	8,050	4,550	
Hardness (calc.)	4,820	4,720	3,260	1,932	2,096	1,542	906	
Weight of 1 c.c.—grams	1.0097 at 20° C.	1.0112 at 20° C.	1.0088 at 20° C.	1.0044 at 20° C.	1.0052 at 25° C.	1.0034 at 25° C.	1.0009 at 25° C.	
Reacting values—milligrams per liter:								
r Ca	74.7	65.0	46.6	29.1	32.2	23.7	14.1	7.3
r Mg	21.5	29.3	18.5	9.5	9.7	7.2	4.0	1.6
r Na	183.9	190.5	184.4	87.8	130.9	103.8	57.3	21.8
r K	.7	.7	.6	.2	.2	.2	.2	
r HCO_3	2.6	7.6	2.9	7.5	2.8	3.0	3.2	5.4
r SO_4	.8	22.8	8.1	4.9	15.7	17.3	11.9	4.8
r Cl	277.5	255.2	239.7	114.5	156.3	115.1	60.7	20.6
Concentration value	561.7	571.1	500.8	253.5	347.8	270.3	151.4	61.5
Reacting values in percent:								
r Ca	13.3	11.4	9.3	11.5	9.3	8.8	9.3	11.9
r Mg	3.9	5.2	3.7	3.8	2.8	2.7	2.7	2.7
r Na (includes r K)	32.8	33.4	37.0	34.7	37.9	38.5	38.0	35.4
r HCO_3	.5	1.3	.6	2.9	.8	1.1	2.1	8.8
r SO_4	.1	4.0	1.6	1.9	4.5	6.4	7.9	7.8
r Cl	49.4	44.7	47.8	45.2	44.7	42.5	40.0	33.4
Concentration value	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

SOURCES OF SAMPLES OF FLOOD WATER LISTED IN TABLE 55

12. Associated Producers Company's Bingham No. 358, in southern part of southeast lobe of Bradford pool.

13. Associated Producers Company's Bingham No. 481, same locality as 12.

14. Associated Producers Company's Bingham No. 479, same locality as 12.

15. South Penn Oil Company's Bingham No. 80, Lot 400, same locality as 12.

16. Sloan and Zook Company's Duke Center No. 14, in east-central part of Bradford pool.

17. Sloan and Zook Company's Duke Center No. 99, same locality as 16.

18. Sloan and Zook Company's Duke Center No. 29, same locality as 16.

19. Petroleum Reclamation Company's Hawkins-Bryner No. 18, in northern part of northwest lobe of Bradford pool.

12 to 18, inclusive, collected by Chas. R. Fettke; sample 19, by Paul D. Torrey; all samples analyzed by U. S. Geological Survey.

When compared with the first flood and connate waters, these analyses show not only a lower concentration but also noticeable differences in chemical composition, such as a higher bicarbonate and sulphate content. The ratio of potassium to sodium is somewhat lower than in the connate water.

Sample 19 has been included to show the composition of a comparatively dilute flood water from a well that was almost "watered out." In this analysis the sodium content has been calculated as previously explained. The theoretical composition of a water of this concentration has been calculated, making the same assumptions as in the case of sample 8 of first flood water. It was found that one part of the connate water and 99 parts of the shallow ground water would give about the same concentration. In such a mixture the composition in terms of reacting values in percent, as compared to the actual values, would be as follows:

	Composition	
	Theoretical	Actual
r Ca	18.2	11.9
r Mg	4.9	2.7
r Na	26.9	35.4
r HCO_3	5.8	8.8
r SO_4	1.0	7.8
r Cl	43.2	33.4

The outstanding feature brought out by this comparison is the high bicarbonate and sulphate content of the actual as compared to the theoretical composition. Torrey thinks that the sulphate content is due to solution of calcium sulphate deposited in the pores of the sand when the oil accumulated. He makes no attempt to explain the high bicarbonate content, assuming apparently that this radicle has been contributed entirely by the shallow ground water introduced into the sand. Many analyses of flood water, however, show a considerably higher bicarbonate content than is present in any of the waters utilized for flooding.

The writer is of the opinion that the pyrite in the sand has contributed a considerable part of the sulphate and also accounts for the excess bicarbonate. The shallow ground water introduced into the sand contains oxygen in solution. When this comes in contact with the finely divided pyrite of the sand, the latter is oxidized to ferrous sulphate and sulphuric acid. The ferrous sulphate oxidizes to ferric sulphate, which is hydrolyzed, giving ferric hydroxide and more sulphuric acid. The ferric hydroxide may become partially dehydrated and remains in the sand as limonite. The following equations represent certain stages in the reactions involved.[52] The sulphuric acid liberated

$$
\begin{aligned}
&FeS_2 + H_2O + 7O = FeSO_4 + H_2SO_4 \\
&2FeSO_4 + H_2SO_4 + O = Fe_2(SO_4)_3 + H_2O \\
&6FeSO_4 + 3O + 3H_2O = 2Fe_2(SO_4)_3 + 2Fe(OH)_3 \\
&Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 3H_2SO_4 \\
&4Fe(OH)_3 = 2Fe_2O_3.3H_2O + 3H_2O
\end{aligned}
$$

reacts with carbonates such as calcite that it comes in contact with, forming calcium sulphate and carbonic acid.

A further comparison of the actual with the theoretical composition indicates that some exchange of sodium for calcium has also taken place in the flood water. Attention has already been called to the fact that the zeolite type of base exchange is reversible. In the more dilute flood waters the tendency is for sodium to go into solution and for calcium to be precipitated.

Some calcium may be precipitated as calcium carbonate as the flood water approaches a producing well owing to the breaking down of the bicarbonate by the loss of carbon dioxide from solution as the pressure drops. This may also cause the deposition of calcium sulphate in the form of gypsum occasionally observed in flood wells.

With one exception, sample 15, all the flood-water analyses studied by the writer that show a high bicarbonate content, also have a high sulphate content. High sulphate content, however, is not necessarily accompanied by high bicarbonate, for reasons stated above.

It is interesting to note that the sum of the reacting values of the negative radicles in each of the seven complete analyses of flood waters shows a slight excess over the sum of the reacting values of the positive radicles. This difference is slight, ranging from .02 to .5 per cent, but the fact that it is always on the negative side suggests rather strongly that a small amount of the positive hydrogen radicle may be present in these waters.

During 1925, the Petroleum Reclamation Company undertook to convert a circle flood that had come onto the northeast corner of its Hawkins property into a line flood. A row of intake wells was established, as shown in Figure 30, and some additional oil wells were drilled. Since the circle flood had been moving onto this area along an irregular front for several years prior to 1925 and many old wells were producing in addition to the new ones, Torrey, in 1926, had an opportunity to obtain samples of flood waters showing relations of concentration and composition to the distance that the water had migrated through the sand as well as changes that it underwent at particular points with the lapse of time. In 1925 it was the practice to admit shallow subsurface water to the sand in the intake walls by raising the casing. In 1926 the flood water was originating at the row of intake wells shown, but considerable flood water had already reached the producing area from the abandoned wells to the northeast.

In Table 56 are assembled two analyses of the shallow ground water used for flooding on the Hawkins property and four analyses of flood water from wells at progressively increasing distances from the source of the flood. The four samples of flood water were taken on the same day. The locations of the wells are shown in Figure 30.

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[52] W. H. Emmons, The enrichment of sulphide ores: U. S. Geol. Survey Bull. 529, pp. 48-65, 1913.

The flood waters exhibit a comparatively rapid increase in concentration with distance from their source. Variations in chemical composition of the salts in solution, although they indicate certain trends, are rather irregular, showing that factors besides distance from source are involved. Sample 8, farthest from the source, represents a first flood water. The extremely low sulphate content of this water would be expected as probably more than half of its volume consists of connate water. The relatively small volume of shallow ground water incorporated with it had its oxygen content depleted long before it reached the well and it had passed beyond the zone of pyrite oxidation before there was an opportunity to take any appreciable amounts of sulphate into solution. Sample 24 shows both a low calcium and a low bicarbonate content, suggesting that some calcium carbonate may have been precipitated, owing to loss of carbon dioxide from solution before the water entered the well.

Table 56. Analyses of ground water and flood water from Petroleum Reclamation Company's Hawkins-Bryner property showing change in concentration and composition with distance from source.

Sample number	20	21	22	23	24	8
Well number	C-4	C-4	10	22	11	12
Date sampled	3-31-26	5-12-26	4-22-26	4-22-26	4-22-26	4-22-26
Average daily oil production—barrels			3.80	.56	.48	.30
Average daily water production—barrels	shallow ground water	shallow ground water	13.68	3.04	.77	.16
Constituents in parts per million						
Radicles:						
Calcium (Ca)	73	68	548	686	452	8422
Magnesium (Mg)	13	13	59	106	172	1460
Sodium (Na) calculated	.6	8	1365	2203	4615	21510
Carbonate (CO_3)	0	0	0	0	0	0
Bicarbonate (HCO_3)	227	234	481	559	392	14
Sulphate (SO_4)	30	28	1039	1990	1416	15
Chloride (Cl)	14	14	2200	3125	7140	52280
Sum	357.6	365	5692	8669	14187	83701
Reacting values—milligrams per liter						
r Ca	3.64	3.39	27.4	34.2	22.6	420.4
r Mg	1.07	1.07	4.9	8.7	14.1	120.0
r Na	.03	.35	59.4	95.8	200.6	935.1
r HCO_3	3.72	3.84	7.9	9.2	6.4	.2
r SO_4	.62	.58	21.6	41.4	29.5	.3
r Cl	.40	.40	62.1	88.2	201.4	1475.0
Concentration value	9.48	9.63	183.3	277.5	474.6	2951.0
Reacting values in percent						
r Ca	38.5	35.3	14.9	12.3	4.8	14.2
r Mg	11.2	11.1	2.7	3.2	3.0	4.1
r Na	.3	3.6	32.4	34.5	42.2	31.7
r HCO_3	39.2	39.8	4.3	3.3	1.4	
r SO_4	6.6	6.1	11.8	14.9	6.2	
r Cl	4.2	4.1	33.9	31.8	42.4	50.0
Concentration value	100.0	100.0	100.0	100.0	100.0	100.0

Samples collected by Paul D. Torrey and analyzed by U. S. Geological Survey.

Changes in concentration of salts in solution in the flood water with respect to time are shown for two wells in Tables 57 and 58. The two wells

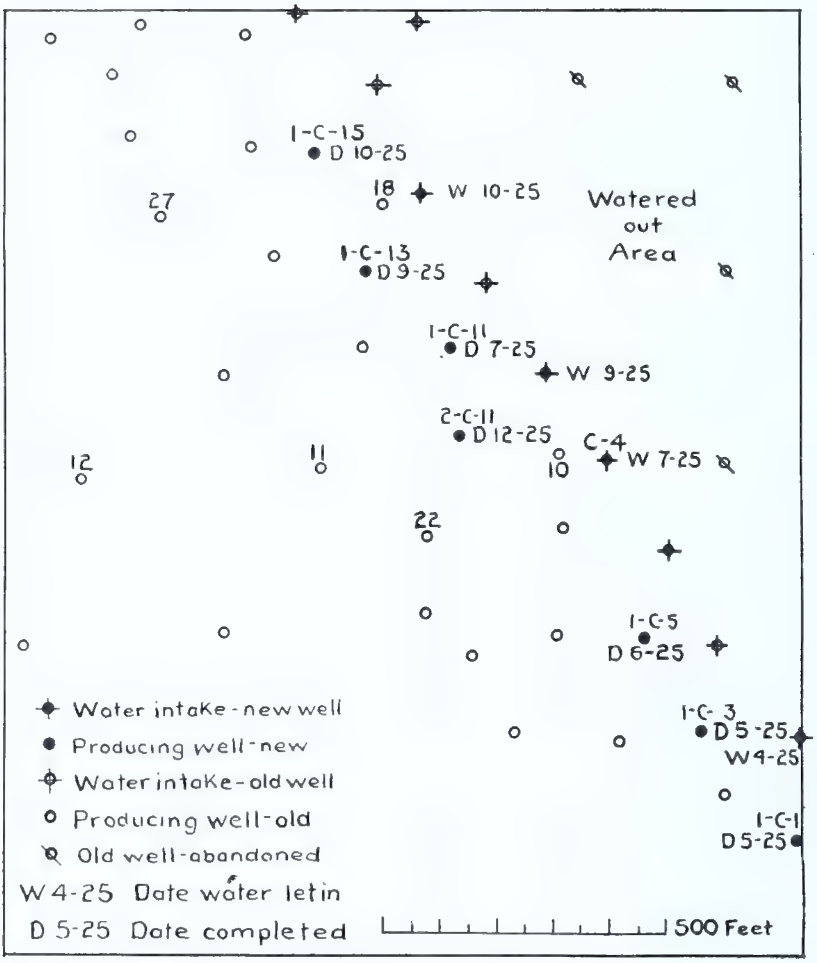

FIGURE 30. Map showing location of wells on the Petroleum Reclamation Company's Hawkins-Bryner property from which flood-water samples were obtained.

are at different stages in the production cycle. No. 10 being much more advanced than No. 11. The reason for this is due to their locations with respect to the advancing flood, as shown in Figure 30. Their oil and water output for the period of 5½ months during which the samples were taken, is given in Table 59.

The flood water from well No. 10 shows a small but steady decrease in concentration during that period, and the salts in solution in the water show comparatively little change in composition.

The flood water from well No. 11, which is much more concentrated, shows a much more rapid decrease in concentration during the same interval. A very marked change in the composition of the salts in solution also occurred during the 5½ months. There is a considerable increase in the amount of sulphate and bicarbonate during the second half of the period. This is accompanied by an increase in calcium and a corresponding decrease in sodium. As has already been pointed out, the calcium content of the salts in solution in the flood waters of this well during the first half of the period was unusually low, probably owing to deposition of calcium carbonate caused by escape of carbon dioxide from solution when the water reached the vicinity of the well. Just what caused this behaviour and why it stopped is not known. Some operating condition may have been responsible.

Table 57. Analyses of flood water from Petroleum Reclamation Company's Hawkins-Bryner No. 10 showing change in concentration with time.

Sample number	25	22	26	27	28	29
Date sampled	3-31-26	4-22-26	4-27-26	5-12-26	6-21-26	9-13-26
Average daily oil production—barrels	4.46	3.80	3.80	3.80	5.26	5.23
Average daily water production—barrels	9.31	13.68	13.68	15.20	17.40	16.35
Constituents in parts per million						
Radicles:						
Calcium (Ca)	436	548	444	458	428	408
Magnesium (Mg)	59	59	50	52	55	55
Sodium (Na) calculated	1563	1365	1409	1326	1310	1238
Carbonate (CO_3)	0	0	0	0	0	0
Bicarbonate (HCO_3)	361	481	395	405	373	340
Sulphate (SO_4)	938	1039	913	909	863	770
Chloride (Cl)	2450	2200	2200	2100	2082	2025
Sum	5807	5692	5411	5250	5111	4836
Reacting values milligrams per liter						
r Ca	21.8	27.4	22.2	22.9	21.4	20.4
r Mg	4.9	4.9	4.1	4.3	4.5	4.5
r Na	67.9	59.4	61.3	57.7	56.9	53.8
r HCO_3	5.9	7.9	6.5	6.6	6.1	5.6
r SO_4	19.5	21.6	19.0	18.9	18.0	16.0
r Cl	69.1	62.1	62.1	59.2	58.7	57.1
Concentration value	189.1	183.3	175.2	169.6	165.6	157.4
Reacting values in percent						
r Ca	11.5	14.9	12.7	13.5	12.9	12.9
r Mg	2.6	2.7	2.3	2.5	2.7	2.9
r Na	35.9	32.4	35.0	34.0	34.4	34.2
r HCO_3	3.1	4.3	3.7	3.9	3.7	3.5
r SO_4	10.3	11.8	10.9	11.2	10.8	10.2
r Cl	36.6	33.9	35.4	34.9	35.5	36.3

Hawkins-Bryner No. 10 well had been pumping flood water for over two years before the first sample was taken.

Samples collected by Paul D. Torrey and analyzed by U. S. Geological Survey.

Table 58. Analyses of flood water from Petroleum Reclamation Company's Hawkins-Bryner No. 11, showing change in concentration and composition with time.

Sample number	30	24	31	32	33	34
Date sampled	3-31-26	4-22-26	4-27-26	5-12-26	6-21-26	9-13-26
Average daily oil production—barrels	.49	.48	.48	.51	.56	.28
Average daily water production—barrels	.77	.77	.77	.79	.88	.50
Constituents in parts per million						
Radicles:						
Calcium (Ca)	741	452	440	454	810	681
Magnesium (Mg)	207	172	153	166	124	118
Sodium (Na) calculated	5933	4615	3987	4594	3392	2890
Carbonate (CO_3)	0	0	0	0	0	0
Bicarbonate (HCO_3)	612	392	532	418	764	608
Sulphate (SO_4)	1676	1416	1353	1373	2207	1851
Chloride (Cl)	9468	7140	6062	7112	4950	4284
Sum	18637	14187	12527	14117	12247	10432
Reacting values milligrams per liter						
r Ca	37.0	22.6	22.0	22.7	40.4	34.0
r Mg	17.0	14.1	12.6	13.7	10.2	9.7
r Na	257.9	200.6	173.3	199.7	147.5	125.7
r HCO_3	10.0	6.4	8.7	6.9	12.5	10.0
r SO_4	34.9	29.5	28.2	28.6	46.0	38.5
r Cl	267.0	201.4	171.0	200.6	139.6	120.8
Concentration value	623.8	474.6	415.8	472.2	396.2	338.7
Reacting values in percent						
r Ca	5.9	4.8	5.3	4.8	10.2	10.0
r Mg	2.8	3.0	3.0	2.9	2.6	2.9
r Na	41.3	42.2	41.7	42.3	37.2	37.1
r HCO_3	1.6	1.4	2.1	1.5	3.2	2.9
r SO_4	5.6	6.2	6.8	6.1	11.6	11.4
r Cl	42.8	42.4	41.1	42.4	35.2	35.7

Hawkins-Bryner No. 11 had been pumping some flood water for about one year before the first sample was taken.

Samples collected by Paul D. Torrey and analyzed by U. S. Geological Survey.

Table 59. Oil and water production of Hawkins-Bryner Nos. 10 and 11 wells during time flood water samples were collected.

Production in barrels Period 1926 From	To	Well No. 10 Production in barrels Oil	Water	Well No. 11 Production in barrels Oil	Water
March 31	April 22	84	297	10.6	16.9
April 22	April 27	19	68	2.4	3.9
April 27	May 12	57	222	7.5	11.8
May 12	June 21	181	652	21.4	33.4
June 21	Sept. 13	447	1,397	42.1	81.1
Total March 31	Sept. 13	788	2,636	84.0	147.1

Six analyses of flood waters from the first line of new oil wells drilled in connection with the C-flood have been tabulated in Table 60 to show the relation of concentration and composition to the production history of the wells with respect to both oil and water. They are arranged in the order of increasing concentration. Although these wells were spaced fairly uniformly with respect to the later intake wells, their individual production varied widely owing to the irregular advance that the flood water had already made into this area from the old circle flood.

Table 60. Analyses of flood water from Petroleum Reclamation Company's Hawkins C-flood line well showing relation of concentration and composition to production history.

Sample number	35	36	37	38	39	40
Well number	1-C-11	1-C-5	1-C-13	1-C-15	2-C-11	1-C-3
Average daily oil production—barrels	.71	1.62	.91	3.08	2.33	2.58
Average daily water production—barrels	6.55	8.16	2.64	3.18	1.59	.95
Total oil production—barrels	227	2090	379	1082	1059	524
Total water production — barrels	2645	1871	602	751	379	192
$\frac{\text{Water}}{\text{Oil}}$ ratio	11.7	.9	1.6	.7	.4	.4
Constituents in parts per million:						
Radicles:						
Calcium (Ca)	256	455	532	934	777	1223
Magnesium (Mg)	35	72	86	129	136	216
Sodium (Na) calculated	1100	2061	2587	3100	4063	5213
Carbonate (CO_3)	10	12	0	0	0	0
Bicarbonate (HCO_3)	262	232	268	258	158	176
Sulphate (SO_4)	643	1218	1312	2227	1747	2044
Chloride (Cl)	1625	3144	4050	5012	6652	9218
Sum	3931	7194	8835	11660	13533	18090
Reacting values milligrams per liter						
r Ca	12.8	22.7	26.6	46.6	38.8	61.0
r Mg	2.9	5.9	7.1	10.6	11.2	17.8
r Na	47.9	89.6	112.5	134.8	176.6	226.7
r HCO_3	4.3	4.2	4.4	4.2	2.6	2.9
r SO_4	13.4	25.4	27.3	46.4	36.4	42.6
r Cl	45.8	88.7	114.4	141.4	187.6	260.0
Concentration value	127.1	236.5	292.3	384.0	453.2	611.0
Reacting values in percent						
r Ca	10.1	9.6	9.0	12.1	8.6	10.0
r Mg	2.2	2.5	2.5	2.8	2.5	2.9
r Na	37.7	37.9	38.5	35.1	38.9	37.1
r HCO_3	3.3	1.8	1.5	1.1	.6	.5
r SO_4	10.6	10.8	9.4	12.1	8.0	7.0
r Cl	36.1	37.4	39.1	36.8	41.4	42.5

Samples collected September 13, 1926, by Paul D. Torrey and analyzed by U. S. Geological Survey.

In general, the concentration shows a steady decrease as the total amount of water produced increases. Samples 37 and 38 afford the only exception, their order being reversed. The well from which Sample 37 came has produced considerably less oil than the one from which Sample 38 came, indicating that the water is probably moving through a rather thin layer of the sandstone and hence, although the total quantity is less, it has been diluted more.

SOURCE ROCKS AND ORIGIN OF PETROLEUM AND NATURAL GAS

The organic theory of the origin of petroleum and associated natural hydrocarbon gases is almost universally accepted by geologists today. According to this theory the oil and gas have been derived from chemically organic debris buried in the sediments. The exact nature of this organic material, whether it was mostly of plant or of animal origin, whether the lower or the higher orders were the principal contributors, what constituents in the organisms' tissues were the chief source, are questions that have not yet been definitely answered. Neither is the mechanism of the reactions by which the organic debris was converted into petroleum and hydrocarbon gases in nature as yet fully understood.

The fact that petroleum deposits are associated with marine sedimentary rocks makes it reasonable to assume that the organic debris from which they were derived was deposited under marine conditions. Considerable field evidence points toward the remains of the lower orders of plant and animal life, mostly of the floating type rich in hydrogenous substances, such as, for example, the diatoms and certain algae among the plants and foraminifera among the animals, which lived in great numbers in the waters in which the sediments accumulated, as more likely mother substances of petroleum than the higher types of vascular plants from whose remains, under favorable conditions, coal deposits have been formed, or the higher types of animals whose organic parts are usually consumed by scavenging organisms before there is an opportunity for burial. Colloidal organic matter swept into the sea by streams may have been another important source.[52]

Trask[53] has found that the organic content of recent sediments consists chiefly of nitrogenous compounds and lignin-humus complexes. Nitrogenous constituents which comprise 40 percent of the organic constituents, are about equally divided between easily hydrolyzable compounds and resistant complexes. Amino-acids and water-soluble proteins constitute a very minor part of the organic matter. Resistant non-nitrogenous complexes comprise about one-third the organic content. Simple compounds devoid of nitrogen form only 10 percent of the organic constituents. Pigments, waxes and other substances soluble in alcohol comprise 5 percent. Carbohydrates, including celluloses and sugars, are absent in most marine sediments; but some shallow-water deposits, particularly those near swamps, have 2 percent of the organic content in the form of carbohydrates. Oils and fats comprise a very minor part of recent marine sediments.

Trask and Wu[54] found no evidence of the occurrence of liquid petroleum in recent marine sediments of the type that might be considered source beds of petroleum and, therefore, conclude that petroleum present in newly deposited sediments is not an important factor in the genesis of oil.

Although petroleum apparently does not form from the organic debris in the sediments until after their burial, micro-organisms present in the sea water and the upper layers of the sediments probably initiate biochemical changes that facilitate the generation of petroleum later on. Hammar[55] states that bacteria probably do not form petroleum directly from the organic material but they seem to favor its formation, both by reducing the quantity of the nitrogenous and carbohydrate compounds in the sediments, and by the formation through decomposition of simple organic compounds which subsequently may polymerize to form higher hydrocarbons and oils. In addition, the bacteria tend to lower the oxygen, nitrogen and sulphur content of the organic matter in the sediments. In this way, the deposits are changed to a form more closely resembling petroleum and are probably rendered more susceptible to the generation of oil by purely chemical action induced by heat, pressure, and time after burial.

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[52] Colin C. Rae, Organic material of carbonaceous shales: Bull. Am. Assoc. Petroleum Geologists, vol. 6, pp. 333-341, 1922.

[53] Parker D. Trask, Deposition of organic matter in recent sediments: Problems of Petroleum Geology, Am. Assoc. Petroleum Geologists, pp. 30-31, 1934.

[54] Parker D. Trask and C. C. Wu, Does petroleum form in sediments at time of deposition: Bull. Am. Assoc. Petroleum Geologists, vol. 14, pp. 1451-1463, 1930.

[55] Harold E. Hammar, Relation of micro-organisms to generation of petroleum: Problems of Petroleum Geology, Am. Assoc. Petroleum Geologists, pp. 35-46, 1934.

From what is now known, therefore, it seems that burial of the organic debris, after a certain amount of biochemical decomposition has occurred, is essential to the formation of petroleum. Trask[56] has observed that the organic content of recent sediments on the sea floor varies with texture. Where the overlying water furnishes a constant supply, clays have double the average organic content of silts, and silts twice that of fine sands. This is in line with the views held by most geologists, namely, that the organic debris was originally deposited in the finer sediments such as the clays and shales, that the petroleum was generated in these beds after burial, and that as compaction and induration progressed, it migrated to the coarser, more porous beds, such as the sandstones, which acted as the reservoir rocks.

Whether micro-organisms in the original sediments continued their activities after burial is still a debatable question. As White[57] has pointed out, the principal physical factors causing the alteration of the solid organic substance after burial are heat, pressure and time. Other probable factors are depth of burial, catalysts, enzymes, and chemical associations, such as the inorganic constituents of the sediments and particularly the connate waters with their dissolved salts. Besides giving loading weight, depth of burial affects both the degree of temperature and the rate of radiation. White stresses, in particular, the importance of horizontal thrust pressure, such as accompanies mountain making movements.

Two theories have been advanced to account for the migration of the oil generated in the source beds to the reservoir, namely, the compaction and the replacement. According to the compaction theory, which was first suggested by Munn,[58] as the loose water-saturated muds that constituted the source beds underwent compaction with increasing load, the water was squeezed out of them into the more porous, less compactible beds, such as the sands, and passed along them either to the outcrop or upward across the bedding toward the surface. It is thought by adherents of this theory that by this process, oil droplets and gas bubbles that have formed in the source beds are carried out of these beds with the currents of water so established into the reservoir rocks where they are eventually accumulated into commercial pools under favorable structural conditions by the water circulation or gravitational forces.

According to the replacement theory proposed by McCoy,[59] on the other hand, connate or mixed water from the reservoir rock entered the source bed after the oil had been generated in it and forced the oil back into the reservoir, the oil in the source bed being replaced by an equal volume of water. Such replacement is possible because the adhesive tension between water and the capillary walls of the source rock is much greater than that between the oil and the walls, and the displacement pressure of the water caused by this greater adhesive tension exceeds the surface tension at the oil-water interface and the cohesive tension of the oil itself. This causes small globules of oil to become separated from the oil column in the capillary and to be forced back inside the now water-lined portion of the capillary tube. As the water pushed ahead in the capillaries to replace more oil and more water entered from the reservoir rock, the oil particles eventually passed back to the reservoir rock from which the water came. McCoy believes that, except for vertical adjustments of the oil after it reached the reservoir owing to differences in the specific gravity of oil and water, the further movement of the oil in the reservoir was slight.

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[56] Parker D. Trask, op. cit. p., 30, 1934.

[57] David White, Metamorphism of organic sediments and derived oils: Bull. Amer. Assoc. Petroleum Geologists, vol. 19, pp. 589-617, 1935.

[58] Malcolm J. Munn, The anticlinal and hydraulic theories of oil and gas accumulation: Econ. Geol., vol. 4, p. 520, 1909.

[59] Alex. W. McCoy, Brief outline of some oil accumulation problems: Bull. Amer. Assoc. Petroleum Geologists, vol. 10, pp. 1015-1034, 1926.

In searching for the source beds of a large oil pool, such as the Bradford, the question arises as to what are the criteria by which such beds can be recognized in the field. Is it necessary that the beds from which the oil has come still retain appreciable percentages of organic matter or could this have been converted largely into petroleum and natural hydrocarbon and other gases during the period of oil genesis and migrated out of the beds.

The marine shales directly associated with the Bradford Third sand contain only very small percentages of organic matter today, although the inorganic hard parts of some of the higher types of organisms, such as the shells of brachiopods, etc., are present in considerable abundance.

In the lower part of the Chemung group, about 500 feet below the Bradford Third sand, the Dunkirk shale member, which is about 200 feet thick in the Bradford district, contains interbedded layers of black shale that constitute about ten percent of its total thickness. The percentage of black shale increases to the northwest, although the member itself thins in that direction. Along the shores of Lake Erie at Dunkirk, the member consists of 55 feet of black shale of which the lower 35 feet, shown in Plate 19, are particularly rich in organic matter, as witnessed by their deep black color.

Below the Dunkirk black shale horizon, very dark gray and black shales make up most of the Rhinestreet and Middlesex members of the Portage group, the Genesee formation, and the Hamilton group.

In order to obtain some idea of the amount of organic matter still present in the different types of shales comprising the Upper and Middle Devonian section in this part of Pennsylvania, the organic carbon was determined in four samples of cuttings from different horizons in well No. 3737 of the United Natural Gas Company, south of Kane, No. 10 of the deep wells. The total carbon in these samples was first determined in a combustion furnace similar to that used in making ultimate analyses of coal.[60] The carbon in carbonates was then determined by the method described by Hillebrand.[61] The difference between the total carbon and that in carbonates represents the carbon present in organic constituents in the shales.

A sample of greenish-gray shale from a depth of 2,275 feet, 70 feet below the Kane sand, had an organic carbon content of only .09 percent; one consisting mostly of greenish-gray shale, but with some intermingled black shale from a depth of 2,782 feet, from the Dunkirk shale horizon, contained .42 per cent of organic carbon; one consisting mostly of brownish-black shale from a depth of 4,084 feet, representing the Rhinestreet horizon, 1.95 percent; and

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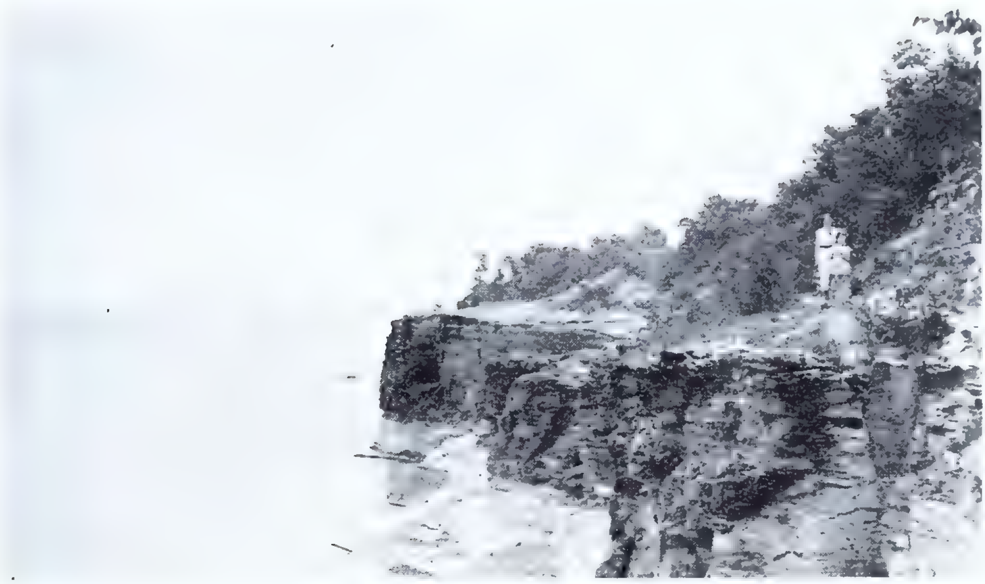
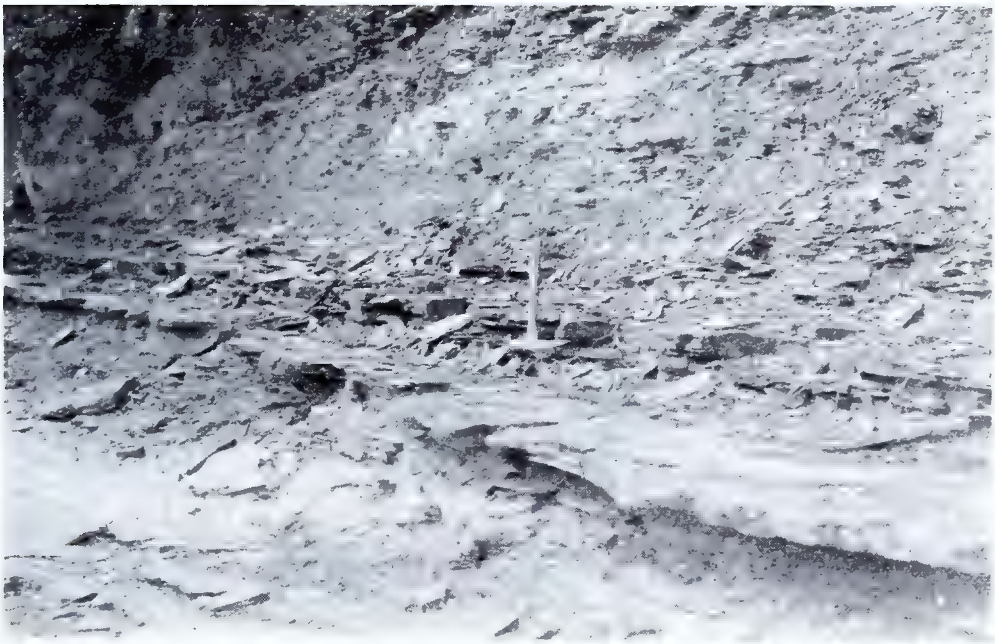
[60] Frederick S. Stanton and Arno C. Fieldner, Methods of analyzing coal and coke: U. S. Bur. Mines, Tech. Paper 8, pp. 15-19, 1926.

[61] W. F. Hillebrand, The analysis of silicate and carbonate rocks: U. S. Geol. Survey, Bull. 700, pp. 217-219, 1919.



A. Outcrop of Dunkirk black shale at Dunkirk, N. Y.



B. Outcrop of Long Beards Riffs sandstone, half a mile south of Fillmore, Allegany County, N. Y.

one consisting mostly of black shale, from a depth of 5,250 feet, representing the Marcellus formation of the Hamilton group, 4.52 percent.

The above analyses indicate that throughout much of Middle and Upper Devonian time appreciable quantities of organic debris were entombed in the muds that were deposited over the region. From how far down in this thick series of shales oil migrated upward into the Bradford Third and other productive sands of the Bradford district, is a moot question. Examinations of cuttings from wells in the district show that in much of the area the Bradford Third sand is the first good reservoir rock above these black shales. Sandstones, to be sure, occur below this horizon but they are, for the most part, very fine-grained and today, at least, possess very low porosities and permeabilities. Shows of both oil and gas are encountered now and then in drilling through these sands, but only occasionally is any commercial production obtained.

If the oil of the Bradford pool originated from the relatively small amounts of organic debris entombed in the shales in close association with the Bradford Third sand, it must have formed at relatively moderate temperatures. As has already been pointed out, there is only one pronounced erosional unconformity in the section above the Bradford Third sand, namely, that which occurs at the top of the Knapp formation. If the entire thickness of Mississippian strata, which is absent in the Bradford district, but present in southwestern Pennsylvania, be assumed to have been originally deposited over the district also, but removed by erosion before the deposition of the Olean conglomerate, the sand would have been buried to a maximum depth of about 3,000 feet at the end of Mississippian time. Assuming a temperature gradient with depth similar to that which exists in the region today, would mean a temperature of only about 100° F. or 38° C. The load weight would have been equivalent to about 3,400 pounds per square inch. Similarly if it is assumed that the entire section of Pennsylvanian and Permian rocks remaining in southwestern Pennsylvania was originally deposited over the Bradford district, the sand at the close of the Paleozoic era would have been buried to a depth of about 4,500 feet. The temperature would have been about 125° F. or 52° C. and the load weight about 5,000 pounds per square inch. The load pressures were no doubt considerably augmented by horizontal thrust pressures, particularly during the Appalachian revolution which marked the close of the Palezoic era.

The fact that large accumulations of oil are found today in strata as recent as Pliocene in age, would seem to indicate that the generation of oil in the Upper Devonian sediments of the Bradford district and its migration into the reservoir rocks may already have been well underway during Mississippian time and perhaps even nearly completed by the close of that period. Additional pressures due to deeper burial later on and the accompanying rise in temperature and particularly the great horizontal thrust pressures that were brought to bear upon the strata during the Appalachian revolution undoubtedly caused important changes in the character of the oil which had already accumulated and may have caused additional quantities to enter the reservoir.

Changes in the composition of the connate water apparently occurred either prior to or concomitantly with the migration of the oil into the reservoir rock as the vestiges of connate water still clinging to the pore walls of the oil-saturated portion of the sandstone are almost identical in composition, if not in concentration, to the connate water around the margins of the pool, as witnessed by the initial flood water from Neath Bolton No. 63 well, water analysis 10. The Bradford Third sand in this well has an elevation only 100 feet below that of the highest point on the Knapp Creek dome.

RELATION OF PETROLEUM AND NATURAL GAS ACCUMULATION TO THE PHYSICAL CHARACTERISTICS OF THE SAND AND THE STRUCTURE

It has been pointed out that in the Bradford district, the area of thick sand development at the Bradford Third horizon coincides very closely with the outlines of the pool. Along the margins of the pool, the shale layers interbedded with the sandstone increase in thickness and the sandstone layers become thinner and fewer. Farther from the pool, only one or two comparatively thin lenses of sand are recognized at the Bradford Third horizon and, in some places, the development of sand is so insignificant that its presence is not recognized by the driller, and other sandstones above or below it are mistaken for it. Sand at this horizon, however, is not confined entirely to the district. To the northeast, east, southeast, and south, sandstones at what is considered to represent about the same horizon occur over a considerable area beyond the limits of the district. Whether these sand bodies are actually continuous with the sandstone in the Bradford district is problematic. Even if they are identical in stratigraphic position, which cannot be proved positively, there are no doubt considerable intervening areas where no sand was deposited. West and northwest of the district, the Bradford Third sand disappears from the section. Although the Laona sandstone of western New York may occur at very nearly the same horizon, there is no evidence to indicate that it is continuous with the Bradford Third.

The occurrence of an unusually thick sand body at the Bradford Third horizon was, therefore, a factor of major importance in the accumulation of the Bradford oil pool, although no doubt the structural features also were important factors in the migration of the oil to its present position, the outlines of the pool conforming as closely to the structure as the sand conditions permit.

It must also be remembered in this connection that much of the oil may have entered the reservoir prior to the close of the Mississippian when the present structural features did not exist. Even taking into consideration, however, that structural features at the time of oil accumulation were probably more nearly like those shown in Figure 7 than those of Plates A and E, the limits of the pool were controlled more by sand conditions than by the structure.

At the extreme northeast edge, production terminates at the 450-foot contour, while at the extreme southwest tip of the southeast lobe, the top of the sand has an elevation of only 40 feet above sea level. At the close of the Mississippian period, this difference was probably only 100 feet instead of 400 feet.

In the northwest lobe, production on the northwest extends to the axis of the West Branch syncline, but on the southeast it does not extend far beyond the axis of the Bradford anticline. Similarly, production along the southeast lobe extends to the axis of the Big Shanty syncline on the northwest but terminates at a considerable elevation above the axis of the Ormsby syncline on the southeast. In the non-productive area on the southeast flank of the Bradford anticline, between the two lobes, where some of the steepest dips in the field occur, the Bradford Third sand is thin and interstratified with numerous shale layers.

The anomalous occurrence of the connate water with respect to the present elevation of the sand around the margins of the pool and in the non-productive area between the two lobes, which has been described under the occurrence of water in the sand, is probably due in part at least to the fact that between the time when the oil accumulated and the present structure developed, the permeability of the sand around the margins of the pool was so reduced by cementation and metamorphism that a new adjustment of the oil-salt water contact was impossible. An alternate explanation is that the numerous sand lenses of the Bradford Third sand are not continuous, hence no perfect alignment of the edge water at a definite level around the margins of the pool was possible. If this is the case, lateral migration in the Bradford Third sand could not have been an important factor in the accumulation of the vast volume of oil present in the Bradford pool.

Over much of the Knapp Creek dome in the northeast part of the field, the upper 35 to 40 feet of the Bradford Third sand originally contained considerable volumes of gas and little or no oil. The sand in much of this area has a total thickness of 90 feet. Another similar gas area was found under a low dome on a structural nose southwest of Rixford. Here the upper 20 to 25 feet of sand were gas-bearing, the total thickness ranging from 45 to 70 feet. Both these occurrences are in good adjustment with the present structure.

The locations of the smaller pools in the Bradford Third sand east, southeast, and south of the main pool are primarily controlled by the presence of more or less local lenses of sand at this horizon. Similar sand conditions also, to a considerable degree, control the location of other small pools in the district that produce from horizons above and below the Bradford Third.

In the Ormsby pool, oil occurs in that portion of the Bradford Third sand along and immediately adjacent to the axis of the Ormsby syncline, and gas occurs in that portion extending up onto the flank of the Smethport anticline. Most of the production in this pool has come from the Kane sand, which yields oil in the down dip part a short distance southeast of the axis of the Ormsby syncline and gas in the up dip part on the flank of the Smethport anticline.

The Lewis Run pool is on the relatively steep southeast flank of the Bradford anticline. It yields oil from the Lewis Run sand in the down dip portion and formerly yielded gas from the up dip portion.

In conclusion, it can be stated that the occurrence of the oil and gas in the Bradford district conforms to the modern conception of the structural theory of accumulation. The gas, oil and salt water in the reservoir rocks are arranged according to their specific gravities in conformity with the structure to the extent that the physical nature of the reservoir rocks permitted, at the time that migration ceased, the gas being found on the higher parts of the structure, then the oil, and finally the salt water if present. The reasons for some of the apparently anomalous features have been discussed.

DESCRIPTION OF INDIVIDUAL POOLS

It is estimated that the total area from which oil has been produced in the Bradford district covers about 100,000 acres, of which 84,000 acres are included within the limits of the Bradford pool. This estimate is based upon a planimeter measurement of the area of the Bradford pool and the smaller pools productive in the Bradford Third sand on a map drawn to a scale of 2,000 feet to the inch, on which the boundaries of the various pools had been carefully located. The areas of the smaller pools of the district producing from the higher and lower sand horizons were measured in a similar manner on a map drawn to a scale of one mile to the inch. The Bradford pool naturally overshadows all of the others. It can reasonably be assumed that at least 84 percent of the natural, as distinguished from the flood, production of the entire district, has come from it.

Bradford Pool

About 86 percent of the 84,000 acres of the Bradford pool lies in Pennsylvania and 14 percent in New York. Within the limits of the pool, practically the entire production has come from the Bradford Third sand. On the northwest side several small Bradford Second sand pools either partially or entirely overlap the main pool, but their area is not more than 500 acres.

The boundaries of the Bradford pool and of the smaller pools whose production comes from the Bradford Third sand are shown on Plates A and E. The large pool is oblong on the northeast and splits into two prominent lobes on the southwest side.

The gas caps occur in the northeastern area, a large one usually referred to as the Knapp Creek dome, and another considerably smaller one which will be referred to hereafter as the Rixford dome. In these two domes the upper portion of the sand originally contained large volumes of gas and little or no oil. The approximate boundaries of the two gas caps are shown in Plate E.

An estimate of the quantity of oil remaining in the Bradford Third sand after the economic limit by ordinary production methods had almost been reached and the total oil originally in the pool has been made. In this connection, the pool has been divided into three parts, namely, the northeast area, the northwest lobe, and the southeast lobe. The two gas-bearing areas have been considered separately. Also in each one of the three main areas, certain parts were separated in which the sand is somewhat thinner, of lower porosity, and usually more interbedded with shale. These, what might be considered marginal, areas are not confined to the edge of the pool—one, for example, divides the southeast lobe longitudinally into two parts.

The entire area had already been divided into squares, one mile on a side, and a great many well records had been obtained for each square in connection with the structure mapping. An average thickness for each square mile was computed from the sand thicknesses shown by the records. Only a part of the total thickness of sand shown by the drillers' record, however, is oil-bearing sandstone. A percentage factor was, therefore, applied to the average thickness in each square mile, which was based upon the percentage of sandstone shown to be in that part of the field by the examination of cores and drill cuttings. The average thicknesses for the different areas into which the pool had been divided were then calculated from the above averages. The average porosities and saturations assigned to each area are based upon analyses made by the writer of cores that were considered to be typical of that particular area. The results have been tabulated in Table 61.

Table 61. Estimate of oil content of Bradford Third sand in Bradford pool after natural production had been removed but before water-flooding started.

Part of pool	Acres	Average thickness Feet	Average porosity Percent	Average saturation Percent	Barrels
Northeast area	22,500	30	14.4	44	331,790,000
Northwest lobe	13,500	29	14.3	44	191,100,000
Southeast lobe	14,000	26	15.4	44	191,350,000
Knapp dome	7,000	31	13.7	33	76,110,000
Rixford dome	1,500	28	13.7	33	14,730,000
Marginal areas	25,500	22	13.2	42	241,290,000
Total					1,046,370,000
Estimated natural production of Bradford pool					203,600,000
Total oil originally present in Bradford pool					1,249,970,000

It is realized that these figures can represent only a rough approximation, but they are believed to be conservative. In view of the fact that the estimate is based upon independently gathered data and arrived at by a somewhat different procedure, the agreement between it and the estimate of 936,174,000 barrels of oil in place after first drilling and before water-flooding, made by the Pennsylvania Grade Crude Oil Association for the Cole Congressional Oil Investigating Committee, is comparatively close.[62] In making the latter estimate, about 9,000 acres apparently were omitted which the writer has included under marginal areas. This accounts for part of the difference between the two estimates.

Guffey or Kinzua Creek Pool

The Guffey or Kinzua Creek pool is along the axis of the Simpson anticline south of the Bradford pool. The anticline, which has been plunging rather gently toward the southwest, increases in pitch at this locality and forms the rather prominent structural nose shown on Plate A. It is apparently open toward the northeast.

Oil production is confined to the Bradford Third sand over an area of about 5800 acres. Core 21 was taken in this pool. Considerable salt water and only small quantities of oil occur in the non-productive interval which separates this pool from the Bradford. Salt water also occurs in the sand around its southern margins.

Oil was discovered in the Guffey pool in 1878. Some of the earlier wells are reported to have started off at 30 to 100 barrels of oil per day. Water-flooding has been experimented with locally on a relatively small scale, but no extensive water-flooding operations are under way in 1935. Indications are that portions of this pool can probably be flooded successfully.

Along the northern margin of the pool, some gas has been obtained from the Kane sand. A well drilled in 1929 had an open flow of 175,000 cubic feet per day and a reservoir pressure of 750 pounds.

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[62] S. H. Cathcart, Oil and gas development in Pennsylvania, 1934, Trans. Am. Inst. Min. Eng., vol. 114, p. 372, 1935.

Ormsby Pool

The Ormsby pool is on the southeast flank of the Ormsby syncline. The pool, which was discovered in 1891, has been a more important producer of gas than of oil. Its location, southeast of the Bradford pool, is shown on Plate D.

Gas and oil have been obtained from both the Bradford Third and Kane sands in this pool, the Kane sand being the more important. The productive area in the Bradford Third sand includes about 3,200 acres of which 1,800 acres have yielded oil and 1,400 acres gas only. The oil occurs in that portion along and immediately adjacent to the axis of the Ormsby syncline, and the gas in that portion extending up onto the flank of the Smethport anticline.

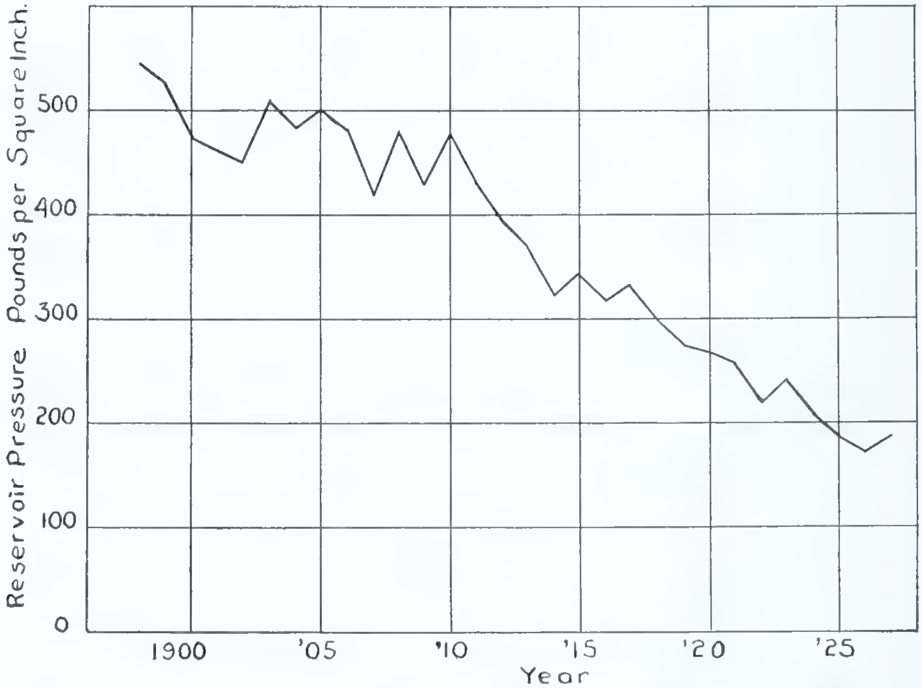

FIGURE 31. **Curve showing decline in reservoir pressure in Ormsby pool.**

The Bradford Third sand has an average thickness of 29 feet in the oil-producing portion of the pool and 19 feet in the gas-bearing area. The records indicate that considerable shale is interbedded with it. Because no well was drilling when the writer investigated the area, it was not possible to get first-hand information on the characteristics of the sand. Oil production has been small, the initial production of the wells having ranged from one to ten barrels. Several rather large gas wells were in the Bradford Third sand. One drilled in 1905 had an open flow of 2,700,000 cubic feet per day and a reservoir pressure of 570 pounds.

The productive area in the Kane sand is a short distance southeast of the axis of the Ormsby syncline on the lower flank of the Smethport anticline. It includes about 5,000 acres, of which 1,200 acres have yielded oil and 3,800 acres gas only. The oil occurs along the northwest side, which is the lowest structurally.

The average thickness of the Kane sand in the oil-producing area is 28 feet and in the gas-bearing area, 16 feet. No first-hand information on the characteristics of the sand was obtained. Oil production has been comparatively small, the initial yield of the wells having been about the same as from the Bradford Third sand.

The Kane sand has been an important producer of gas in the Ormsby pool. The gas has been developed on a conservative basis, largely by one company, which extended the period of active drilling from 1896 to 1915. Gas wells in the Kane sand had initial open flows ranging from 100,000 to 675,000 cubic feet per day. The maximum reservoir pressure recorded was 750 pounds per square inch. The average in 1898 was 545 pounds. The decline in reservoir pressure for the period from 1898 to 1927 is shown in Figure 31. This is based upon data obtained through the courtesy of the United Natural Gas Company. The fluctuations shown are due largely to two causes. During the earlier years additional wells were being drilled which extended the limits of the pool. The pressures recorded in these wells were usually somewhat higher than those of the old wells and the general average was, therefore, raised. Another cause is that it was not always feasible to allow sufficient time to elapse for pressures to become equalized before taking the readings. Wells drilled in 1914 and 1915 still had initial open flows of 100,000 to 175,000 cubic feet per day.

Some salt water occurs in both the Bradford Third and Kane sands in the Ormsby pool. About two-thirds of the gas wells are equipped with pumping units to raise the water which enters them from the producing sands.

Marvin Creek Pools

Three small Bradford Third sand oil pools have been developed along the Marvin Creek valley above Smethport on the northwest flank of the Smethport anticline. They include a productive area of about 300 acres. Local lenses of sand at the Bradford Third horizon apparently determine their locations. The sand averages about 20 feet in thickness and has considerable shale interbedded with it. Oil production has been small, although several wells are reported to have started at 15 to 35 barrels a day. In some of the wells considerable gas and only a little oil has been encountered.

In the middle one of the three pools, a little oil has also been obtained from the Haskell sand which here is 12 feet thick. The type locality for the Haskell sand is along the Marvin Creek valley at the southwest edge of Smethport. The original Haskell well, drilled in 1877, was still producing a little oil in 1929.

Windfall Pool

The Windfall pool is on a structural terrace on the southeast flank of the Knapp Creek dome, as shown on Plate A. It covers 1,000 acres. It was formerly believed that the production in the Windfall pool came from a sand below the Bradford Third.[63] The stratigraphic and structural studies made in this region by the writer, however, have shown that the productive sand in the Windfall pool occurs at the same horizon as the Bradford Third sand.

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[63] Jerry B. Newby, Paul D. Torrey, Charles R. Fettke, and L. S. Panyity, Bradford oil field, McKean County, Pennsylvania, and Cattaraugus County, New York; Structure of Typical American Oil Fields, vol. II, Amer. Assoc. of Petroleum Geologists, p. 422, 1929.

In the Windfall pool, the sand is relatively thin and is split into several layers by shale partings. At least two beds of sandstone are usually reported, an upper one about 12 feet thick and a lower one 10 feet thick, separated by about 14 feet of shale. Sometimes a third layer occurs 10 feet or so below the second and separated from it by about 14 feet of shale. The sand layers usually contain considerable interstratified shale. Oil production has been small. Salt water has been reported in both the upper and middle layers.

Minard Run Pools

Two small pools of about 100 acres are along the Minard Run valley on the relatively steep southeast flank of the Bradford anticline in the otherwise non-productive area that separates the two lobes of the Bradford pool. Production comes from the Bradford Third sand, which is here relatively thin, as shown by core 15 which was taken in the southwest pool. Only a small amount of oil along with considerable quantities of salt water has been produced.

Bennett Brook, West Branch and Marilla Brook Pools

Along the northwestern edge of the Bradford pool several small oil pools have been developed in the Bradford Second sand. These cover about 500 acres. The locations of these pools seem to be determined by the occurrence of a series of comparatively thick sandstone lenses at the Bradford Second sand horizon. Only part of the sandstone, however, is oil-bearing. Much of it is very tightly cemented and salt water frequently is present in the lower portion.

In the small pool near the mouth of Bennett Brook, the sand has an average thickness of 40 feet. At the forks of Marilla Brook and the West Branch of Tunungwant Creek, the average thickness is also 40 feet, with about 18 feet oil-bearing. About one mile up Marilla Brook on the south side the average thickness is 50 feet, with about 15 feet oil-bearing, and on the north side, 35 feet. In the productive areas, the initial yield of wells in the Bradford Second sand was frequently as high as 25 barrels per day and the wells have proven to be long-lived.

Beyond the belt of Bradford Second sand pools, which has a northeast-southwest trend, occurs another belt in which several small gas pools were at one time active. The gas was usually in the uppermost part of the sand and was underlain by salt water. Initial production in some instances was high. One well in the small pool along the State line on the divide between Bolivar Run and Bennett Brook had an open flow of ten million cubic feet per day. It was soon drowned out by salt water, however. A well drilled in 1926 along Gilbert Run at the lower end of the reservoir had an initial open flow of 200,000 cubic feet per day and a reservoir pressure of 155 pounds. Salt water was also present in the sand at this locality. The area had previously been exploited for gas but the old wells had been abandoned. As far as the writer knows, there is no gas production in this area in 1935.

Lewis Run Pool

The Lewis Run pool, discovered in 1909, occupies about 1,800 acres in the borough of Lewis Run and adjacent territory on the southwest. Structurally, it is on the relatively steep southeast flank of the Bradford anticline. Apparently a local occurrence of a sandstone of suitable characteristics to act as a reservoir rock at a horizon 100 feet below the Bradford Third sand, holds the pool.

The area is the type locality for the Lewis Run sand and within the limits of the pool the oil production has been confined almost entirely to it. The oil-producing portion covers about 800 acres on the down-dip side. Initial production of the wells ranged from one-half to eight barrels. In some wells a little salt water occurred with the oil.

In the gas-bearing area on the up-dip side, some wells had initial open flows of 65,000 to 390,000 cubic feet per day. The gas resources of the pool are now exhausted.

A little oil has been obtained from the Bradford Second sand just south of the Erie Railroad station in the borough of Lewis Run, and a sand at the Chipmunk horizon has yielded some gas in the area west of the Lewis Run sand occurrence.

Other Pools of the Bradford District

North of the Bradford pool considerable oil has been obtained from the Chipmunk sand along Chipmunk Creek and from both the Chipmunk and Bradford Second sands along Nichol Run in the towns of Carrolton and Allegany, Cattaraugus County, New York. The Chipmunk pool was opened in 1895 and reached a peak daily production of 2,600 barrels. Some wells are reported to have had initial daily productions of 250 barrels.

The Sugar Run or Watsonville pool is 3½ miles west of the Bradford pool in the southeast part of Corydon Township, McKean County. Production comes from the Sugar Run sand. This pool was opened in 1897. Some of the wells were of the gusher type. Water-flooding on a small scale has proven fairly successful.

It is estimated that the area from which oil has been recovered in the Chipmunk, Nichol Run, and Sugar Run pools is about 4,500 acres, bringing the total productive acreage of the Bradford district to about 100,000 acres.

WATER RESOURCES

When it is realized that it takes an average of seven to eight barrels of water to produce one barrel of oil, the importance of an adequate supply of water for carrying on flooding operations on the scale used in the Bradford district at once becomes apparent. To produce 11,990,250 barrels of oil from the district in 1934 required a quantity of water sufficient for the needs of a city of 100,000 inhabitants.

Prior to 1928, practically all water-flooding was done by admitting shallow subsurface water to the intake wells by raising the casing. The source, therefore, consisted of water which was already stored in the ground under the tract being flooded plus annual accretions from the local rainfall. With the exception perhaps of properties along narrow divides, the quantity of water in this upper zone was usually adequate for the type of slow-moving floods then used. It is not sufficient, however, for the later intensive floods.

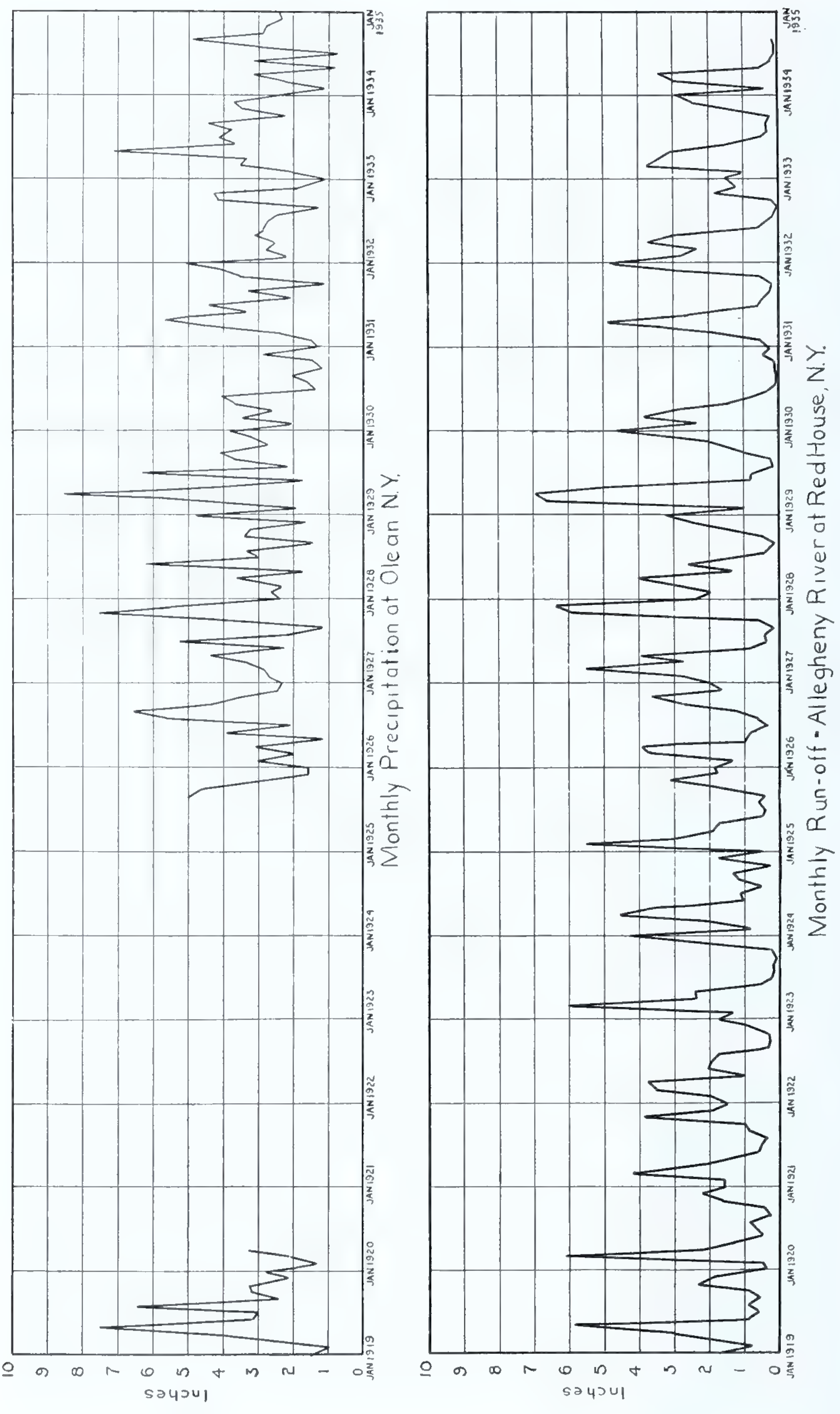

FIGURE 32. Monthly precipitation at Olean, New York, and monthly run-off measured along Allegheny River at Red House, New York.

PRECIPITATION AND RUN-OFF

The Bradford district fortunately is in a region of abundant rainfall so that the problem of finding enough water to carry on the present extensive flooding operations has not been a serious one, although it has been necessary in recent years to supplement local supplies with water from outside the district.

The annual precipitation from 1926 to 1934 at Olean, New York, 12 miles northeast of Bradford, the nearest point at which records have been kept, is given in Table 62. Precipitation throughout each year by months is shown in Figure 32. Most of the precipitation is in the form of rain. The amount contributed by snowfall varies considerably from winter to winter. Both the table and figures are based upon data on file at the Pittsburgh station of the United States Weather Bureau. The variations from a minimum of 29.33 inches in 1934 to a maximum of 46.89 inches in 1929, which occurred during the nine year period, have an appreciable effect upon the supplies of water available for flooding. During the drought years of 1930 and 1934, local supplies on some properties became so low that the problem of obtaining sufficient water to maintain the input rate was a serious one.

The run-off from the Upper Allegheny River basin above Red House, New York, which covers a drainage area of 1,690 square miles and includes most of the Bradford district, is also shown in Table 62 and in Figure 32. It was compiled from data published in the surface water supply papers of the United States Geological Survey relating to the Ohio River basin. Figue 32 emphasizes the fact that the run-off is practically always low during the summer and autumn months.

Table 62. Annual precipitation at Olean, New York and annual run-off from Upper Allegheny River basin at Red House, New York.

Year	Precipitation Inches	Run-off Inches	Year	Precipitation Inches	Run-off Inches
1919	40.69	21.83	1927	42.98	31.71
1920	station closed	16.94	1928	34.67	21.35
1921	" "	20.42	1929	46.89	29.89
1922	" "	17.16	1930	29.51	17.14
1923	" "	17.63	1931	36.76	17.91
1924	" "	22.28	1932	35.24	21.01
1925	" "	20.86	1933	42.22	19.50
1926	38.98	22.70	1934	29.33	

Surface Water

The use of surface water for flooding in the Bradford district has been practically negligible. In a few isolated cases creek water has been used as an emergency source when no other water was available but even in those cases its use has not been prolonged. When the water was not filtered, trouble was experienced due to mudding of the sand.

Even if proper settling and filtering equipment were installed, it would be difficult to find an adequate supply of surface water on or near to most properties as most of the streams of the district are small and run very low during the summer and autumn. The quantity of water injected into the sand during the first year's operation of an intensive flood is sufficient to cover the area under development to a depth anywhere from 6 to 33 inches. On many properties, it has amounted to 12 inches or more. The quantity of water required for a particular area during the course of a year, therefore, may exceed the run-off from that area and in some instances even the total precipitation upon it. Large storage reservoirs would be needed to insure an adequate supply.

The city of Bradford with a population of approximately 18,500, normally obtains its water supply from the water sheds of Gilbert Run and Marilla Brook above its junction with the former. These wooded areas west of the city are outside the oil-producing territory. Reservoirs have been constructed along the two streams, one with a capacity of 202,000,000 gallons (4,810,000 barrels) and the other, 100,000,000 gallons (2,380,000 barrels). During the summer and autumn of the two drought years, 1930 and 1934, this storage capacity was inadequate. The use of water in the city had to be considerably curtailed and the supply was supplemented by drilling wells.

Ground Water

Occurrence.

The bed-rock formations underlying the Bradford district, with the exception of the Olean and Knapp sandstones and conglomerates, which are confined largely to the southern part of the field where they cap rather broad divides, contain no well-defined water-bearing horizons. The sandstones below the Knapp are usually fine-grained and shaly. They are low in porosity and permeability and are lenticular. Most of the strata below the Knapp are sandy shale and clay shale. Available subsurface water supplies in these beds are confined to fractures and local sandy lenses in the upper zone whose average lower limit occurs at a depth of 360 feet and rarely extends below 500 feet, regardless of the horizon at which a particular well starts. The topography has a slight influence, the water zone extending to a little greater depth beneath the major valleys where the average limiting depth is 450 feet and rarely exceeds 600 feet. The capacity of this upper zone for holding water is relatively small. Although the quantity of water was usually adequate for the formerly slow-moving floods, the supply is not sufficient for the present intensive floods.

In the southern part of the field in the vicinity of Bingham, water for flooding is obtained from the Olean and Knapp sandstones which cap the broad divides. Wells with capacities up to 600 barrels per day are the source of water for some of the pressure plants in this area.

Fortunately, all the larger valleys of the Bradford district have in recent geologic time been filled with alluvium, in some places, to depths of 250 feet. Ground water draining down the slopes through the loose material covering the hillsides enters the alluvial deposits in large quantities. It then travels very slowly in these deposits in the direction of slope of the old valley floor. As these deposits are still in an unconsolidated condition, they are capable of holding relatively large volumes of water in contrast to the sandy shales and shales that constitute most of the bed-rock. Their permeability is high so that copious flows of water can be obtained from them. A single well will draw upon a relatively large area and interference will result if wells are spaced too close.

Wells drilled to the bottom of the alluvial deposits yield from 600 to 1800 barrels of water per day. In many places water confined in sandy layers

A. Ground water flowing from drive pipe of an abandoned oil well along Kendall Creek valley.

B. Loading a shell with nitroglycerin preparatory to shooting a well.

near the base of such deposits is under sufficient head to rise to the surface when a well penetrates them. It is a common sight along major valleys to see such water rising to the surface between the drive-pipe and casing. In Plate 20A water is shown flowing from the drive-pipe of an abandoned oil well along Kendall Creek valley above Pratt Hollow. Figure 33, showing a cross-section of the lower end of Minard Run valley, illustrates a condition found in many parts of the Bradford field.

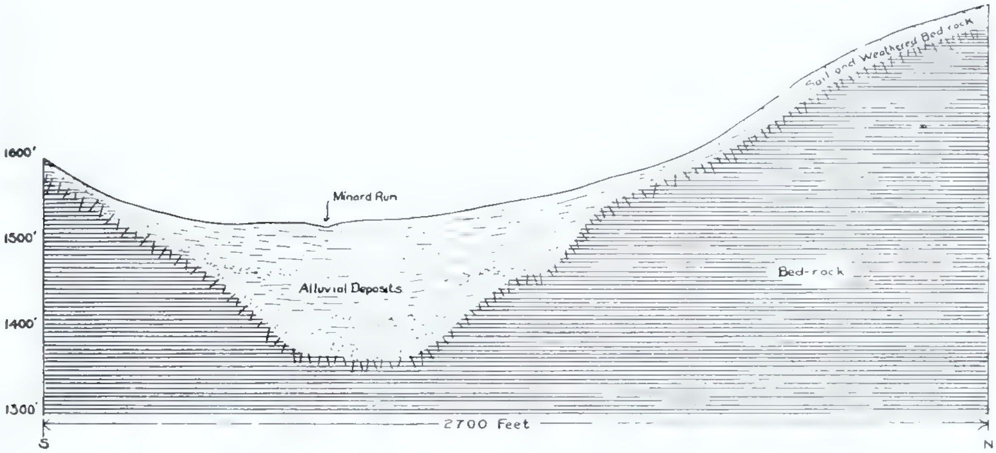

FIGURE 33. Cross-section of lower end of Minard Run Valley.

The quantity of water available from the alluvial deposits along the valleys depends upon several factors. The percentage of well-sorted sand and gravel layers interstratified with the finer silts and clays at any particular locality is an important factor. This was determined in part by the nature of the outcropping rocks that furnished the sediments. In general, the deposits become coarser headward, which means greater porosity and permeability in that direction. Their thickness and width, however, rapidly diminish in that direction, as does the area from which the water collects.

There is a slow downstream movement of water in the alluvial deposits. The removal of water by upstream wells, therefore, has an effect on the capacities of the downstream wells. Just as in a surface stream, the removal of water from the alluvial deposits at one point along a valley reduces the quantity available farther down stream. There is this difference, however, that the subsurface waters move much slower than the surface waters so that the effects are not nearly so noticeable. Also, the capacity of the alluvial deposits for carrying water is limited so that water removed from them up stream may, to a considerable extent, be replenished by water draining into them laterally down the sides of the valley which might otherwise have been lost by surface seepage. Only a definite maximum amount is available from the alluvial deposits of each valley. Precipitation causes this to vary somewhat with the seasons and from year to year.

No detailed survey of the quantity of subsurface water available for flooding in the Bradford district has been attempted in the present investigation. Only a few examples can, therefore, be cited, of the capacities of individual wells or groups of wells in various parts of the district. In the northeast part along Mix Creek, one mile north of the State line, one well supplies a pressure plant operating at about 1,800 barrels per day capacity. Along the North Branch of Indian Creek, just south of the State line, two wells are required to furnish 1,200 barrels daily. Along Oil Valley, half a mile above Duke Center, one well supplies 1,800 barrels daily, while 2½ miles up the valley two wells are required to supply 2,400 barrels. Along Pennbrook Run at Bells Camp three wells yield 4,050 barrels daily. Just below Rixford along the South Branch of Knapp Creek, seven wells furnish 10,000 barrels daily. Along the East Branch of Tunungwant Creek on the flat at South Bradford, three wells supply a pressure plant of 3,500 barrels daily capacity. Along Marilla Brook, below the reservoir, the water department of the city of Bradford operates two wells that yield 4,000 barrels daily. Although the second well was drilled 1,700 feet east of the first, it affected the production of the latter which originally had a daily capacity of 2,400 barrels. During the summer of 1934, the department drilled a well in the city near the Mill Street bridge, one-half mile below the forks of Tunungwant Creek, which is reported to have had a potential capacity of 14,000 barrels per day.

The local sources of water supply are at present augmented to a very considerable degree by the 15-mile water distributing system of the Reclamation Supply Corporation.[64] The trunk pipe-line, 24 inches in diameter with a capacity of 150,000 barrels daily, serves that part of the field on the divide between the Tunungwant and Allegheny drainage as far south as Rew.

The water is obtained from four wells, 1½ miles west of Olean, New York, 60 to 80 feet in glacial sands and gravels that underlie the broad level floor of the Allegheny Valley at this point. In 1934, the company delivered about 50,000 barrels of water daily to about 75 percent of the operators within two miles on each side of the pipe line. The water is sold at a base price of two cents a barrel and is delivered at a pressure equivalent to approximately 1,000 pounds per square inch on the face of the sand.

Composition.

An ideal water for flooding purposes is one containing no substances that will cause the formation and deposition of solid material in the pores of the sand, thereby reducing the permeability of the sand or sealing it off entirely.[65] Apparently some natural waters in the Bradford district are so near this ideal that good results have been attained using them in their raw state. Many of the waters available, however, can be improved by proper treatment.

The most common deleterious substances are extremely fine silt in mechanical suspension and iron in solution. The iron in solution is in a ferrous state, usually as ferrous bicarbonate or sulphate. On coming in contact with air, it oxidizes to the ferric state. The ferric salts are not stable, but hydrolyze, precipitating the iron as ferric hydroxide, which may lose part of its water and form the hydrated ferric oxide, commonly known as limonite. The iron content of the water in the alluvial deposits of the Bradford district varies greatly from place to place. Around some wells where such water issues between the drive-pipe and casing, considerable deposits of limonite accumulate, while around others, no trace can be observed. In domestic water supplies, usually little or no trouble is experienced from precipitation if the iron content does not exceed 0.4 to 0.5 parts per million.[66] Algal growths sometimes develop in the water in storage tanks, which may also tend to clog the pores of the sand.

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[64] C. R. Conine, Pipe line system supplies water for flooding operation in the Bradford, Pa., field: Oil and Gas Jour., vol. 32, pp. 13 and 31, March 22, 1934.

[65] A. S. Behrman, Flood-water purification problems: Oil and Gas Jour., vol. 28, pp. 248-249, March 6. 1930.
L. J. Clarke, Treatment of flood waters in Bradford field for the removal of corrosive suspended matter: Oil and Gas Jour., vol. 32, pp. 16 and 18, Jan. 11, 1934.

Silt can be removed from the water by proper settling and filtration. In order to reduce the iron content to the point where it will not be harmful, the water must be thoroughly aerated before settling and filtering. Efficient aeration will usually precipitate most of the iron, provided the water is relatively free from organic matter. If this is not done, the iron will tend to precipitate in the distributing lines and in the pores of the sand as the water has usually absorbed enough oxygen from the air, in the process of being raised to the surface and pumped under pressure into the distributing lines, to oxidize any iron originally in solution in the ferrous state.

In waters containing iron in solution, iron-depositing bacteria, such as *Crenothrix*, are very likely to grow. These organisms hasten the deposition of iron. They develop in darkness and are, therefore, capable of multiplying in distributing pipes, where they sometimes accumulate to such an extent as seriously to interfere with the service. They have been found more than 1,000 feet below the surface in water wells and it is quite possible, therefore, that they will grow in the face of the sand of intake wells and seal off the pores.

Copper sulphate is commonly used to destroy algal growths as well as other microscopical organisms that may develop in stored water. Three parts per million of copper sulphate will destroy most of the objectionable forms of organisms.[67] It should not be added in excessive amounts because of its possible corrosive effect upon the distributing lines.

Shortly after it became the practice in the Bradford field to admit water into intake wells from the surface by means of distributing lines, it was found that in some cases, in spite of the fact that the water had been carefully aerated, settled, and filtered, considerable amounts of hydrated iron oxides were deposited on the face of the sand. Investigation showed that this iron oxide was a product of corrosion of the steel pipe of the water lines. This brought to the fore the problem of treating the water to prevent corrosion.

Acidity and oxygen in solution are the main causes of corrosion. Iron has a slight tendency to go into solution in water, iron ions taking up a positive charge from hydrogen ions in the water and liberating atomic hydrogen. If the atomic hydrogen is removed, ferrous hydroxide forms, which is only very slightly soluble in water and, therefore, precipitates out, usually oxidizing to the ferric state and forming the yellowish-brown rust that is so objectionable in waters used for flooding. The removal of the iron ions from solution permits more iron ions from the metal to enter the water and the corrosive action continues. The hydrogen may be disposed of in one of two ways. It may combine with the oxygen in solution to form water or, where the acidity of the water is high, it may possibly be liberated as hydrogen gas. In the waters used for flooding purposes, the former usually happens, since they invariably contain an abundance of oxygen.

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[66] F. E. Turneaure and H. L. Russell, Public Water-Supplies, third ed., revised, New York, p. 503, 1924.

[67] F. E. Turneaure and H. L. Russell, idem. p. 511, 1924.

Acidity in the water can easily be corrected by adding an alkaline substance, such as lime. Oxygen, however, cannot be removed readily. Other means have to be resorted to, therefore, to reduce the amount of corrosion. The film of rust which ordinarily forms on the metal surface is too permeable to afford such protection, the soluble iron diffusing through it to the outside water. Corrosion continues forming pits and tubercles. The weakly formed tubercles tend to break off and are swept along by the moving water to the face of the sand.

To retard corrosion, a more impervious coating must be formed. This can be done by producing super-saturation of some compound in the water, such as calcium carbonate, which on precipitation forms a relatively impervious coating. Corroding iron increases the hydrogen ion concentration by removing some of the negative ions, especially the carbonates. If the hydrogen ion concentration and alkalinity of the water have been properly adjusted, the corroding iron may remove sufficient carbonate to increase the hydrogen ion concentration above the solubility equilibrium of calcium carbonate and some of the calcium carbonate will precipitate, forming a fairly tough and impervious film which will act as a protective coating and retard further corrosion. If the membrane thus formed breaks, corrosion continues until a new one is formed, provided the hydrogen ion concentration and alkalinity of the water are kept properly adjusted.

The hydrogen-ion concentration is an expression of the intensity factor of acidity or alkalinity as compared with quantitative alkalinity. On the hydrogen ion or pH scale, a value of 7 represents neutrality. This means that if the material tested has a pH of 7.0, it is neither acid nor alkaline. Values higher than pH 7.0 denote alkalinity and those lower, acidity. The hydrogen ion concentration of a water can be determined in a number of ways. In plant practice, colorimetric methods are commonly used. The alkalinity of a water as expressed in analyses represents its content of carbonates, bicarbonates, and hydroxides. Alkalinity is determined by titration with a standard solution of acid to a certain standard datum point. In determining total alkalinity, methyl-orange is usually employed as an indicator. Results are commonly expressed in terms of the equivalent parts per million of calcium carbonate.

Baylis [68] has prepared a curve showing the relation of hydrogen ion concentration and alkalinity to the proper treatment of water to retard corrosion. Baylis's curve is based upon calcium carbonate in distilled water at 22° C. It is approximately correct for natural waters low in soluble salts. Waters containing appreciable amounts of certain neutral salts, such as the sulphates and chlorides, will change the position of the equilibrium curve and it is, therefore, necessary to construct a curve for each kind of water.[69] According-ing to Baylis,[70] the water must contain at least 25 parts per million of calcium carbonate in order to form a protective coating. Some waters of the Bradford district do not contain this amount.

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[68] John R. Baylis, Prevention of corrosion and "red water": Jour. Am. Water Works Association, vol. 15, p. 624, 1926.

[69] Frank N. Speller, Corrosion, Causes and Prevention, first ed., New York, p. 346, 1926.

One of the essential factors determining whether protective coatings of calcium carbonate will form is the amount of free carbon dioxide present. Protective carbonate coatings are deposited or dissolved according to the reversible reaction:— $Ca\ (HCO_3)_2 = CaCO_3 + H_2O + CO_2$. The free carbon dioxide in excess of the amount necessary to keep the calcium present from precipitating as calcium carbonate, that is, that portion of the free carbon dioxide which is available for the solution of carbonates according to the above equation, can be defined as "aggressive carbon dioxide."

The Von Heyer marble test can be used to show whether a certain water is above or below the equilibrium point.[71] In this test the amount of aggressive carbon dioxide in the water is determined. A half-liter flask is filled to the neck with the water to be analyzed. This should be done at the source from which the sample is taken and every precaution should be observed to eliminate possible contamination of the sample. Several grams of pulverized and well-washed marble are put in the flask. A cork stopper is then inserted, the flask is shaken vigorously and set aside for 1 to 3 days. A 100-cubic centimeter sample of the untreated water is pipetted into an Erlenmeyer flask and titrated for bicarbonate with one-tenth normal hydrochloric acid. Then 100 cubic centimeters of the water which has been treated with calcium carbonate is titrated in the same way. The increase, if any, in the bicarbonate of the treated water is proportional to the amount of aggressive carbon dioxide present. The hydrogen ion concentration and the alkalinity, expressed in terms of calcium carbonate, of the treated sample will give a point on the calcium carbonate equilibrium curve for the particular water tested. Inasmuch as the composition of the water probably will vary over a period of time, the tests should be repeated at intervals until a curve can be established.

When it is desired to form a protective coating of calcium carbonate, lime should be added until the hydrogen ion concentration is slightly higher than that indicated by the test. If too much lime is added, there is danger of forming a calcium carbonate precipitate throughout the solution, which will be carried into the pores of the sand.

Six analyses of ground water from the Bradford district are shown in Table 63. Of these, Nos. 41, 42, and 44 are too low in calcium content to form a protective coating. No. 42 represents an aerated and filtered water to which a little aluminum sulphate had been added as a coagulant. In the analysis, the sum of the reacting values of the negative radicles exceeds that of the positive radicles by 1.1 per cent. This water apparently was corrosive and should have received some lime treatment. Sample 43 shows the extent to which the ground waters in the more intensely developed portions of the district are becoming contaminated with salts from the flood waters which are dumped on the surface.

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[70] John R. Baylis, Treatment of water to prevent corrosion: Indus. and Eng. Chemistry, vol. 19, p. 777, 1927.

[71] Frank N. Speller, idem. pp. 346 and 580.

Table 63. Analyses of ground water from the Bradford district.

Sample number	41	42	43	44	45	46
Constituents in parts per million:						
Radicles:						
Silica (SiO_2)	29	16	35			
Iron (Fe)	.40	.13	.28			
Calcium (Ca)	8.0	6.8	18	15	8.7	38
Magnesium (Mg)	2.6	2.1	6.4	5.2	3.8	10
Sodium (Na)	86	84	165	80*	121*	60*
Potassium (K)	3.0	2.6	1.9	....	....	....
Carbonate (CO_3)	0	0	0	0	26	0
Bicarbonate (HCO_3)	190	185	218	191	242	185
Sulphate (SO_4)	5.4	5.1	7.7	35	13	18
Chloride (Cl)	43	42	176	25	32	68
Nitrate (NO_3)	.20	0	.10	....	....	....
Total dissolved solids	265	246	518			
Reacting values milligrams per liter						
r Ca	.3993	.3394	.8984	.7487	.4342	1.8967
r Mg	.2138	.1727	.5263	.4276	.3125	.8224
r Na	3.7396	3.6526	7.1748	3.3881	5.2596	2.6059
r K	.0767	.0665	.0486	....	....	....
r CO_3	....	....	....	....	.8666	....
r HCO_3	3.1143	3.0324	3.5733	3.1305	3.9664	3.0321
r SO_4	.1124	.1062	.1603	.7287	.2707	.3748
r Cl	1.2127	1.1845	4.9638	.7052	.9026	1.9181
r NO_3	.0032	....	.0016	....		
Concentration value	8.8720	8.5543	17.3471	9.1288	12.0126	10.6500
Reacting values in per cent						
r Ca	4.5	4.0	5.3	8.2	3.6	17.8
r Mg	2.4	2.0	3.0	4.7	2.6	7.7
r Na	42.2	43.2	41.4	37.1	43.8	24.5
r K	.9	.8	.3	.....	....	....
r CO_2	....	....	....	....	7.2	....
r HCO_3	35.0	35.1	20.5	34.3	33.0	28.5
r SO_4	1.2	1.2	.9	8.0	2.3	3.5
r Cl	13.8	13.7	28.6	7.7	7.5	18.0

*Calculated.

SOURCES OF SAMPLES LISTED IN TABLE 63

41. Water well of Associated Producers Company's Bingham Property north of Bingham, Lafayette Township, McKean County. Well 400 feet deep. Water mostly from Pottsville and Knapp sandstones. Sample collected August 14, 1930, by Chas. R. Fettke.

42. Same water as Sample 41, after treating with aluminum sulphate and passing through an International Filter Company style E-60 filter. Sample collected August 14, 1930, by Chas. R. Fettke.

43. Water well of Sloan and Zook Company, in alluvium of Oil Valley, half a mile north of Duke Center, Otto Township, McKean County. Water obtained at a depth of 140 feet. Sample collected by Chas. R. Fettke, August 29, 1930.

44. Water well G. O. 8 on Drake Farm of Forest Petroleum Corporation, in alluvium of East Branch of Tunungwant Creek, south of Bradford, Bradford Township, McKean County. Sample collected for C. J. Jackson, August, 1928.

45. Water well G. O. 9, same locality as 44. Sample collected for C. J. Jackson, August, 1928.

46. Water intake well No. 52 on Hall Farm of Kendall Refining Company, in alluvium along Foster Brook between Derrick City and Red Rock, Foster Township, McKean County. Sample collected by Paul D. Torrey, March 30, 1926.

All samples analyzed by U. S. Geological Survey.

OIL PRODUCTION

TOTAL PRODUCTION OF THE BRADFORD DISTRICT

During many of the more than sixty years of active life of the Bradford field no systematic record was kept of the production that came from within its borders as distinguished from that from adjacent districts. In the published statistics, the production of the New York and Pennsylvania portions were sometimes separated and included with the production of other districts in those States.

The yearly and total production of the district to the end of 1934, as compiled in Table 64 and shown graphically in Figure 34, therefore, had to be, in part, somewhat of an approximation. The figures cover the production from the 100,000 acres of oil-producing territory in the district of which 84,000 acres are included in the Bradford pool.

The production figures for 1871 to 1875 were taken from Table No. 1, page 29 of Report I-5 of the Second Geological Survey of Pennsylvania and from 1876 to 1888 from Table No. 5, page 40 of the same report. The production for 1889 to 1905 was obtained from Mineral Resources of the United States, published by the U. S. Geological Survey, covering those years. According to the older operators in the district, the effects of water-flooding on the total production of the district became noticeable as early as 1907. It has, therefore, been assumed that the decline which followed the period of flush production reached its lowest level in 1906 and that a gradual increase occurred after that year. The figures given for 1906 to 1920 represent estimates by the writer. The estimates for 1921 to 1928 are based upon statistics compiled for McKean County by the Bureau of Statistics of the Pennsylvania Department of Internal Affairs and information obtained from the McKean County assessor's office. On the basis of the relationship of the difference between the total New York and the Richburg pool production to the Bradford district production in Pennsylvania in 1927, it was assumed that the production of

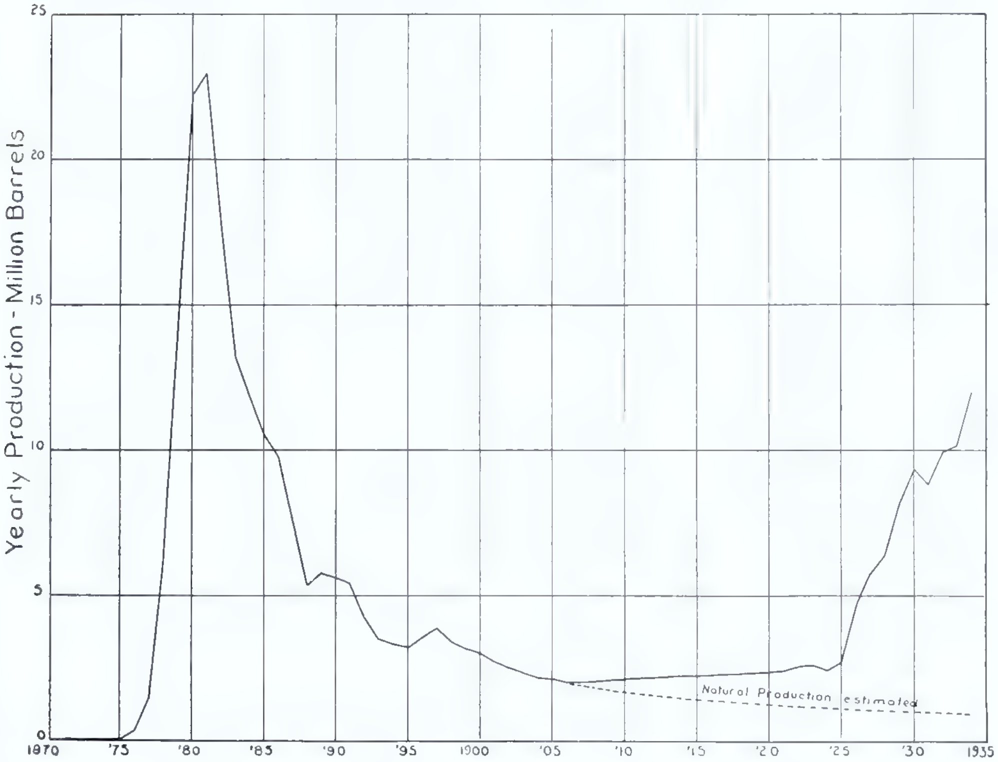

FIGURE 34. **Production curve of the Bradford district.**

the New York portion of the district amounted to ten percent of that from the Pennsylvania portion during this interval. The production for 1929 to 1934 was obtained through the courtesy of the Bradford District Pennsylvania Oil Producers' Association and its predecessor, the Northwestern Pennsylvania Oil Producers' Association.

An estimate of the natural production as distinguished from the production obtained by artificial water-flooding for the period from 1907 to 1934 is also included in Table 64. This was obtained by extending the actual production decline curve from 1897 to 1905 on logarithmic co-ordinate paper.[72] Practically the entire 82,500,000 barrels of flood production has come from the Bradford pool. The natural production, on the other hand, also includes that from the 16,000 odd acres in the district that are outside the limits of the Bradford pool.

Table 64. Total oil production of the Bradford District by years in barrels

Year	Natural
1871	1,000
1872	2,000
1873	2,000
1874	3,000
1875	25,000
1876	382,768
1877	1,468,481
1878	6,208,746
1879	13,914,509
1880	22,212,000
1881	22,945,069
1882	17,959,000
1883	13,294,886
1884	11,883,000
1885	10,564,298
1886	9,752,797
1887	7,580,979
1888	5,306,062
1889	5,765,053
1890	5,608,735
1891	5,452,418
1892	4,291,061
1893	3,502,136
1894	3,359,835
1895	3,244,808
1896	3,604,771
1897	3,904,230
1898	3,444,299
1899	3,206,845
1900	3,022,493
1901	2,757,603
1902	2,506,981
1903	2,326,413
1904	2,187,883
1905	2,115,225
1906	2,022,000
	205,828,384

Year	Natural & flood	Natural (Estimated)
1907	2,048,000	1,925,000
1908	2,074,000	1,848,000
1909	2,100,000	1,774,000
1910	2,126,000	1,704,000
1911	2,152,000	1,644,000
1912	2,178,000	1,589,000
1913	2,204,000	1,519,000
1914	2,230,000	1,452,000
1915	2,256,000	1,439,000
1916	2,282,000	1,393,000
1917	2,308,000	1,357,000
1918	2,334,000	1,324,000
1919	2,360,000	1,292,000
1920	2,386,000	1,257,000
1921	2,415,687	1,229,000
1922	2,577,726	1,200,000
1923	2,602,777	1,170,000
1924	2,480,540	1,143,000
1925	2,747,620	1,122,000
1926	4,725,252	1,098,000
1927	5,793,707	1,072,000
1928	6,361,703	1,056,000
1929	8,137,125	1,034,000
1930	9,334,096	1,012,000
1931	8,812,133	1,000,000
1932	9,964,235	980,000
1933	10,125,458	960,000
1934	11,990,248	940,000
	119,106,307	36,523,000

Total oil production = 324,900,000 barrels
Total natural production = 242,400,000 barrels
Total flood production = 82,500,000 barrels

The natural production of the 100,000 acres comprising the productive area of the Bradford district has been about 242,400,000 barrels, or 2,424 barrels per acre. Of this, 203,600,000 barrels, or 84 percent, can reasonably be assigned to the Bradford pool. On the basis of a total original oil content of 1,250,000,000 barrels, the above figure represents a recovery of only 16 percent of the oil in the pool by the ordinary production methods, which were dependent upon the energy inherent in the reservoir.

The production curve for the Bradford field, shown in Figure 34, thus far is unique in the history of oil field development. More than fifty years after the original peak was attained, the curve is rising steeply and yet the boundaries of the field have not been extended nor has a deeper productive horizon been discovered. The rise is due entirely to the application of a new technique in a field that has been exploited more than sixty years.

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[72] Willard W. Cutler, Jr., Estimation of underground oil reserves by oil-well production curves: U. S. Bur. Mines, Bull. 228, pp. 22-24, 1924.

NATURAL PRODUCTION OF INDIVIDUAL PROPERTIES

Data on the initial production of individual wells and yields per acre by ordinary production methods for individual properties are hard to secure. Since 1875, when original development on an extensive scale started, most properties have changed ownership several times and most of this information has been lost.

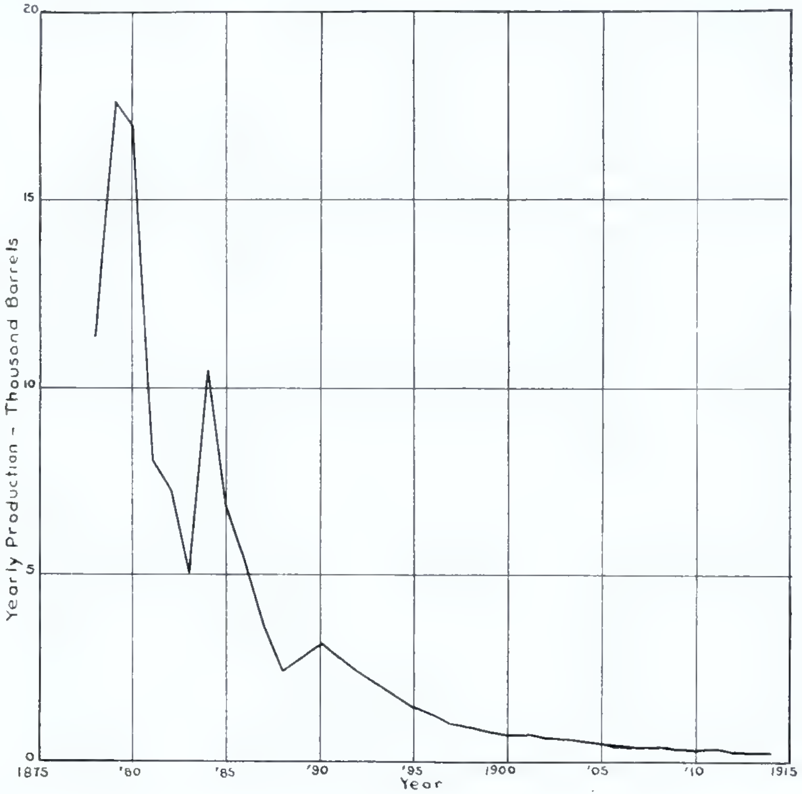

FIGURE 35. Production curve of Bradford lease of Bird and Ball.

Where the information is available, however, a close relation between the physical characteristics of the sand, particularly the porosity, permeability and thickness of oil bearing "pay," and the production data is revealed.

On the Bradford lease of Bird and Ball, consisting of 22.5 acres, half a mile east of Bells Camp in the northeast part of the Bradford pool, which was originally developed by six wells, the natural production averaged 5,450 barrels per acre. The production by years is given in Table 65 and shown graphically in Figure 35. This property is adjacent to the one on which core 4 was taken. The thickness of oil-bearing sandstone ranges from 21 to 27 feet, as compared with 35 to 40 feet on the property from which core 4 came, but the porosity of the sand and other characteristics are the same.

Table 65. Average daily natural production per well and yearly and cumulative production of Bradford lease of Bird and Ball, in barrels.

Year	Daily	Yearly	Cumulative
1878		11,393	11,393
1879	8.05	17,620	29,013
1880	7.72	16,953	45,966
1881	3.73	8,163	54,129
1882	3.32	7,280	61,409
1883	2.30	5,036	66,445
*1884	4.76	10,448	76,893
1885	3.12	6,836	83,729
1886	2.44	5,336	89,065
1887	1.63	3,570	92,635
1888	1.10	2,418	95,053
1889	1.27	2,787	97,840
1890	1.44	3,146	100,986
1891	1.28	2,800	103,786
1892	1.09	2,400	106,186
1893	.96	2,100	108,286
1894	.79	1,733	110,019
1895	.67	1,467	111,486
1896	.57	1,253	112,739
1897	.49	1,067	113,806
1898	.43	933	114,739
1899	.38	838	115,577
1900	.34	751	116,328
1901	.35	767	117,095
1902	.31	684	117,779
1903	.29	630	118,409
1904	.26	580	118,989
1905	.24	517	119,506
1906	.22	481	119,987
1907	.20	427	120,414
1908	.18	405	120,819
1909	.16	358	121,177
1910	.15	331	121,508
1911	.15	329	121,837
1912	.14	300	122,137
1913	.12	261	122,398
1914	.11	237	122,635

*Wells cleaned out.

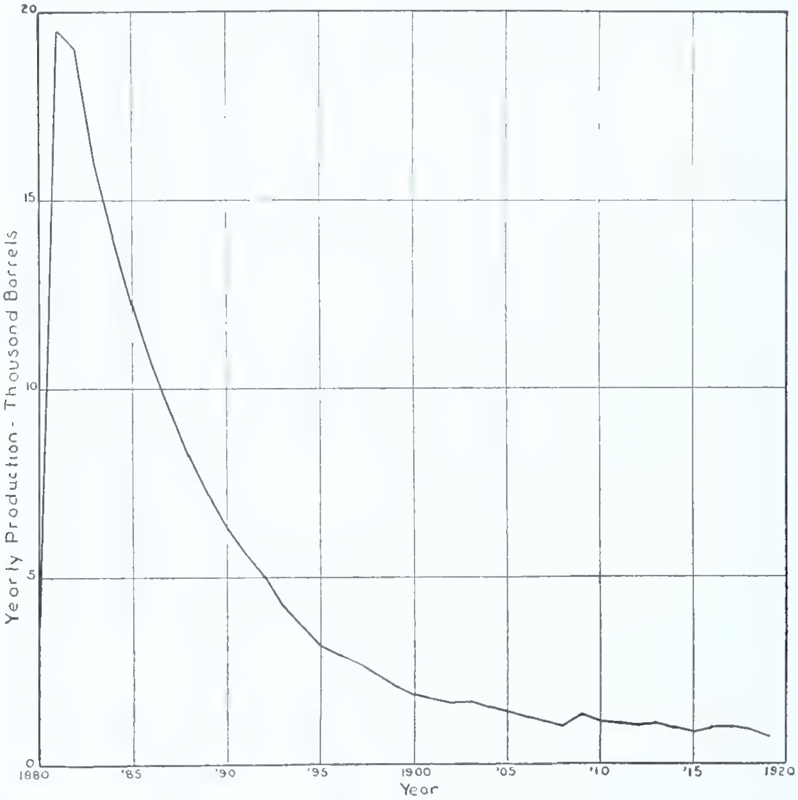

FIGURE 36. **Production curve of Norton farm of J. T. Jones.**

On the Norton farm, formerly owned by J. T. Jones, consisting of 108 acres, half a mile northwest of Rixford, in the northeast part of the field, which was originally developed by 16 wells, the natural production averaged only 1,700 barrels per acre. The production by years is given in Table 66 and shown graphically in Figure 36.

Table 66. Average daily natural production per well and yearly and cumulative production of Norton Farm of J. T. Jones, in barrels.

Year	Daily	Yearly	Cumulative	Year	Daily	Yearly	Cumulative
1880		3,657	3,657	1900	.32	1,886	159,928
1881	3.34	19,510	23,167	1901	.30	1,774	161,702
1882	3.25	19,000	42,167	1902	.28	1,642	163,344
1883	2.77	16,000	58,167	1903	.29	1,680	165,024
1884	2.39	14,000	72,167	1904	.27	1,566	166,590
1885	2.10	12,250	84,417	1905	.24	1,411	168,001
1886	1.83	10,700	95,117	1906	.22	1,279	169,280
1887	1.60	9,350	104,467	1907	.20	1,168	170,448
1888	1.40	8,200	112,667	1908	.18	1,035	171,483
1889	1.23	7,200	119,867	1909	.22	1,304	172,787
1890	1.08	6,300	126,167	1910	.20	1,154	173,941
1891	.96	5,600	131,767	1911	.19	1,095	175,036
1892	.86	5,031	136,798	1912	.17	1,018	176,054
1893	.73	4,246	141,044	1913	.19	1,082	177,136
1894	.63	3,688	144,732	1914	.16	955	178,091
1895	.54	3,157	147,889	1915	.15	895	178,986
1896	.50	2,931	150,820	1916	.16	960	179,946
1897	.47	2,736	153,556	1917	.17	972	180,918
1898	.41	2,386	155,942	1918	.16	913	181,831
1899	.36	2,100	158,042	1919	.13	773	182,604

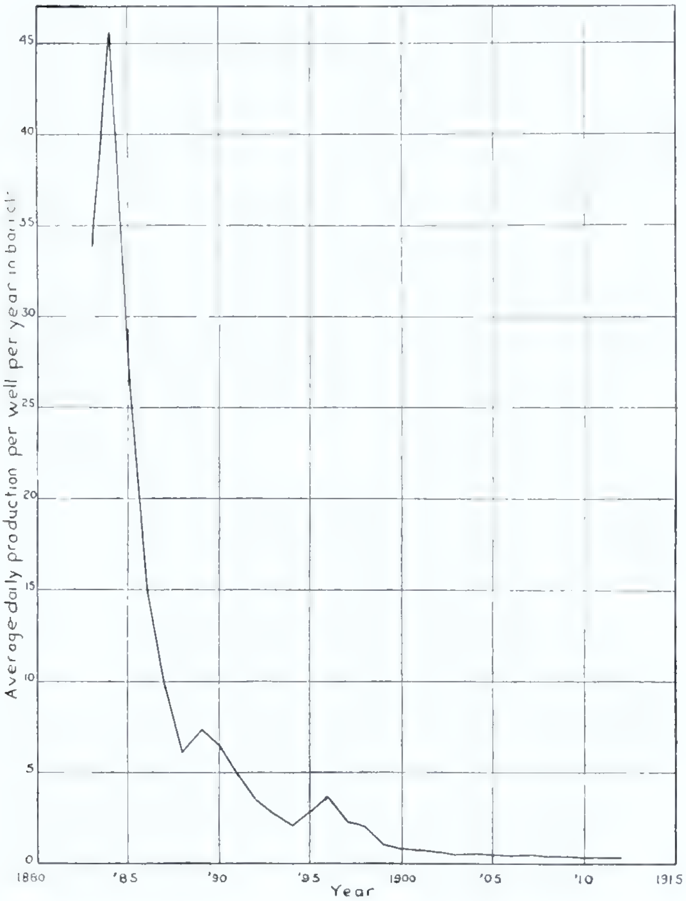

FIGURE 37. Curve showing average daily production per well by years for Bingham Estate property of the Associated Producers Company.

On the Bingham Estate property of the Associated Producers Company, consisting of 1,322 acres, of which 1,225 acres have produced oil, the natural production averaged 2,830 barrels per acre. This property is between

Simpson and Bingham in the southern part of the southeast lobe. An elongated body of thick sand containing a so-called "loose streak" occupies about one-fourth of the tract. Cores 18 and 19 are representative of this portion of the property; core 20 is more typical of the balance. One of the original

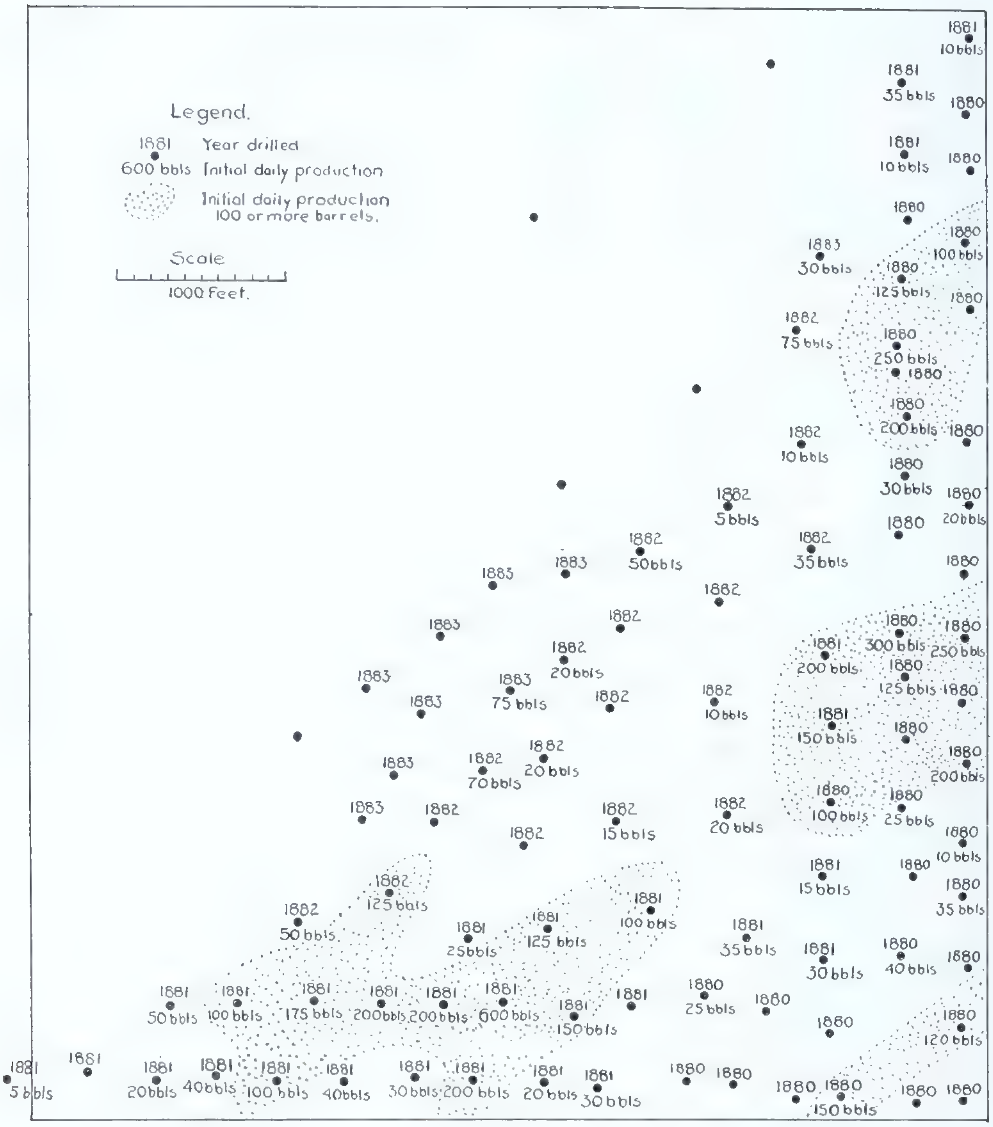

FIGURE 38. **Map showing location and initial production of original wells on part of the Moody tract of the Minard Run Oil Company**

wells in the thick sand body produced 495 barrels of oil during the first 24 hours after it was shot. The production[73] by years is given in Table 67, and the average daily production per well by years is shown graphically in Figure 37.

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[73] H. R. Pierce, Oil and gas reserves: Am. Pet. Inst., Div. of Production, Report 826-3R, pp. 56-57, June, 1930.

Table 67. Average daily natural production per well and yearly and cumulative production of Bingham Estate, property of the Associated Producers Company, in barrels, and number of producing wells.

Year	Daily	Av. No. of wells	Yearly	Cumulative	Year	Daily	Av. No. of wells	Yearly	Cumulative
1883	33.96	6.16	76,309	76,309	1898	1.16	174.73	73,839	3,001,132
1884	45.62	18.38	306,677	382,986	1899	.99	177.00	64,141	3,065,273
1885	26.99	43.97	433,107	816,093	1900	.79	176.49	50,913	3,116,186
1886	15.04	58.37	320,481	1,136,574	1901	.72	176.00	46,287	3,162,473
1887	9.72	65.62	232,669	1,369,243	1902	.63	176.00	40,404	3,202,877
1888	6.12	58.08	130,062	1,499,305	1903	.47	176.00	30,143	3,233,020
1889	7.36	74.59	200,406	1,699,711	1904	.52	176.82	33,387	3,266,407
1890	6.57	105.30	252,325	1,952,036	1905	.49	175.00	31,447	3,297,854
1891	4.99	129.14	235,413	2,187,449	1906	.45	175.00	28,864	3,326,718
1892	3.46	139.00	176,183	2,363,632	1907	.43	175.00	27,448	3,354,166
1893	2.76	147.30	148,357	2,511,989	1908	.40	175.00	25,397	3,379,563
1894	2.13	156.00	121,276	2,633,265	1909	.39	175.00	24,663	3,404,226
1895	1.81	162.63	107,620	2,740,885	1910	.35	175.00	22,349	3,426,575
1896	1.60	175.00	102,249	2,843,134	1911	.33	174.39	20,896	3,447,471
1897	1.32	175.00	84,159	2,927,293	1912	.31	174.33	19,541	3,467,012

In most of the Bradford pool the initial production of the wells was comparatively small, being usually less than 50 barrels, and they had to be pumped from the start. Flowing wells were mostly around the northeast margin of the Rixford gas cap and in the southeast lobe. According to Hugh Grant, one of the old operators in the field, what was perhaps the largest well in the Bradford pool was located on lot 481, warrant 2,280, half a mile southwest of Aiken. This well averaged 760 barrels of oil per day for the first 20 days. On a property adjacent to the one on which core 16 was taken, some of the original wells had an initial production of 350 barrels. Some large wells, up to 495 barrels, were drilled in the area from which cores 18 and 19 came. All these large wells were in areas where portions of the sand have high porosities, 20 percent or more by volume. In most of the field porosities in excess of 16 percent are rare.

Many of the large wells of the field were in the vicinity of Allen and Aiken. The initial production of the original wells for which records were available, on a portion of the Moody tract of the Minard Run Oil Company in the vicinity of Allen is shown in Figure 38. These wells are along the northwest margin of the southeast lobe. It will be observed that the large wells occupy more or less elliptical areas whose long axes trend approximately parallel to the axis of the lobe and that the individual areas also tend to be aligned more or less along this trend. Cores taken in similar areas of large initial production have shown that in them the sand body contains lenses of sandstone of higher porosity, slightly coarser texture, and much higher permeability than the average for the pool as a whole. The trend of the long axes of these lenses was determined by the direction of the currents which transported the sand to its present position.

Mention has been made several times of the two gas caps in the northeast part of the pool. In the Knapp Creek dome area, McMullen and Hallock, on May 30, 1877, struck a large flow of gas in the upper 25 feet of the Bradford Third sand on the Loup farm, now the Quinlan property, along the North Branch of Indian Creek in Section 1, town of Olean, in Cattaraugus County, New York. Ashburner[74] made a careful measurement, on June 1, 1877, of the rate of discharge of the gas from this well and estimated it at

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[74] Chas. A. Ashburner, Petroleum and natural gas in New York State. Trans. Am. Inst. Min. Eng., vol. XVI, pp. 939-940, 1888.

24,480,000 cubic feet per 24 hours. About one barrel of oil a day accompanied the gas. The discharge of gas diminished continuously until 1882. After that the well produced 2 to 3 barrels of oil per day with only a comparatively small amount of gas. Apparently the gas was allowed to exhaust itself by blowing into the air.

WATER-FLOODING

Historical Summary

John F. Carll, geologist of the Second Geological Survey of Pennsylvania in charge of the survey of the oil regions, was the first to call attention to the possibilities of employing water-flooding to increase the recovery of oil from oil sands. In a report published in 1880 he makes the following statement:[75]

"The flooding of an oil district is generally viewed as a great calamity, yet it may be questioned whether a larger amount of oil cannot be drawn from the rocks in that way than by any other, for it is certain that all the oil cannot be drawn from the reservoir without the admission of something to take its place.

If one company owned all the wells drawing upon a pool, and had accurate records of the depths and characteristics of the oil-producing stratum in each well, it is quite possible that some system might be devised by which water could be let down through certain shafts, and the oil forced toward certain other shafts, where pumps were kept in motion, and thus the rocks be completely voided of oil and left full of water."

In the Bradford district, the discovery that by introducing water into one well, the production of surrounding wells could be greatly increased was probably made accidentally. After flush production of the eighties, many wells were abandoned. In some wells the casing was pulled without properly plugging them and in others the casing corroded and admitted fresh water from shallow horizons to the sand. In certain areas where water had thus accidentally gotten access to the sand, an increase in production in adjacent wells occurred.

Just when and on what property or properties this discovery was made is not definitely known. One of the earliest floods is reported to have started two miles southeast of Rew in the Cole Creek district and another, one mile northeast of Aiken. In both these areas so-called "loose streaks" are present in the sand which would make the effects of water-flooding more quickly noticeable. As soon as the cause of this increase was understood, water-flooding began to be practiced secretly by some of the operators.

Intentional water-flooding was probably practiced on a small scale as far back as the early nineties. For a long time floods were started simply by shooting, cutting, or pulling the casing in an oil well which was no longer profitable to operate and letting the water in on the producing sand. It was found that in many instances neighboring wells were benefited by the resulting water-drive. A certain number of additional wells were usually drilled around the area of advancing water as the old wells were spaced too far apart for efficient flooding. Later it was discovered that much better results could be obtained by tubing the water intake wells, as otherwise they soon became filled with silt and cavings from the walls to a level above that of the sand, thereby preventing access of the water to the sand. This method of applying the water-drive came to be known as the "circle" type of flood.

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[75] John F. Carll, The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties, Report III, Pennsylvania Second Geological Survey, p. 263, 1880.

According to the older operators in the district, it was not until about 1907 that the effects of flooding became appreciably noticeable in the annual output of the district. For a long time many of the operators did not approve of introducing water into the sand and most of the larger companies opposed it. Those who did engage in the practice did so more or less secretly as the Pennsylvania law requires that all abandoned wells and dry holes be plugged in such a manner as to prevent water entering the oil and gas sands. This was construed as prohibiting flooding.

In 1921, the Pennsylvania legislature passed a special act legalizing the practice when applied to the Bradford and certain other specifically named sands. Section 3 of this act[76] reads as follows:

"The owner or operator of any well or wells which produce oil or gas from the strata known as the "Bradford Sand," "Kane Sand," and "Haskell Sand" shall be permitted to allow such wells to remain open for the purpose of introducing air, gas, water, or other liquid pressure upon said "Bradford Sand," "Kane Sand," and "Haskell Sand" for the purpose of recovering the oil and gas contained therein, provided that the introduction of such pressure of air, gas, water, or other liquid into said "Bradford Sand," "Kane Sand," and "Haskell Sand" shall be through casing or tubing which shall be so anchored and packed that no other oil or gas bearing sand, above or below said "Bradford Sand," "Kane Sand," and "Haskell Sand" shall be affected by the introduction of such pressure."

In 1923, this act was amended by adding the names "Ball Town Sand," "Clarendon Sand," and "Cherry Grove Sand" to those already included in Section 3.[77] In 1929, the "Glade Sand" was added to the list.[78]

Water-flooding was greatly extended after the passage of this act and the methods of applying the water-drive underwent rapid improvement. The old "circle" flood, as generally developed in the Bradford field, had always been a more or less haphazard operation. Realizing this, the Forest Oil Company in 1922 started what came to be known as the "line" type of flood. This consisted of two rows of oil wells staggered on both sides of an equally spaced line of water intake wells extending across a property. In this type of flood, the wells in the rows were spaced from 200 to 220 feet apart and the rows 100 to 130 feet. When a row of oil wells had about reached its economic limit of production, which usually happened within two or three years, another row was drilled on the outside of it with the wells again in staggered position. The former oil wells were then converted into water intakes. The "line" flood, with various modifications to suit individual property conditions, came to be generally adopted throughout the Bradford field until, in 1928, it in turn was superseded by the still more intensive method, called the

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[76] An act to regulate the drilling, operating, and abandoning of oil and gas wells, and providing a penalty for violation of this act. Approved May 17, 1921. Laws of the General Assembly of the Commonwealth of Pennsylvania passed at the Session of 1921, pp. 912-915.

[77] Act No. 88. Approved May 1, 1923, Laws of the General Assembly of the Commonwealth of Pennsylvania passed at the Session of 1923, p. 115.

[78] Act No. 352. Approved April 26, 1929. Laws of the General Assembly of the Commonwealth of Pennsylvania passed at the Session of 1929, p. 821.

"five-spot" on account of the resemblance of the pattern to the five spots on dice, which is now employed on practically all new development work.

In the "five-spot" method the whole tract that is to be developed is laid out in a pattern of squares. Water intake wells are placed at the corners of the squares and producing wells at their centers. The first "five-spot" operation in the Bradford field was attempted by the Associated Producers Company on a property in the southern part of the field as early as 1924. The idea was Frank Haskell's. Unfortunately, the water intake wells were spaced 500 feet apart. This was too far to give any appreciable results, as a core taken in the area since has shown that the sand is fairly tight and, therefore, requires a considerably closer spacing. In cleaning out the water intake wells later to find out what was wrong, it was also discovered that they had not been tubed properly and that silt had accumulated in the lower portion, effectually sealing off the sand to the entrance of water. It was, therefore, not until late in 1927 and early in 1928, when the "five-spot" development undertaken by Arthur E. Yahn of Olean on the Kuno-Kuhn property near the head of Oil Valley in the northeastern part of the field commenced to show results, that the possibilties of the method were demonstrated. Since that time its use has spread rapidly.

A further development associated with the introduction of the "five-spot" method of flooding has been the application of additional hydraulic pressure to that of the hydrostatic head of the column of water in the intake well. This is accomplished by introducing the water under pressure at the top of the well by means of pumps. While this had already been tried out as far back as 1925 and 1926 in both the Richburg and Bradford pools with rather promising results, the old style flooding methods were not particularly well suited to its use and these experiments, therefore, did not attract much attention until 1928 when John Messer of Bolivar, New York, realizing the ideal conditions that the "five-spot" flood afforded for the application of additional pressure, tried it out on a property in the Richburg pool that the Messer Oil Company was then developing. The results obtained were so satisfactory that the introduction of subsurface water into intake wells has now become obsolete as far as new development work is concerned. The wells are tubed to take water from the surface only and usually in such a manner that 400 to 1,200 pounds pressure, and in some instances more, per square inch at the top of the well can be applied. This type of flooding has come to be known as the "pressure flood."

One of the great advantages of the "five-spot" method is that it permits a much more rapid return of the capital invested in the exploitation of a particular tract than did the "circle" or "line" flood. In view of the high cost of acreage in the Bradford pool in recent years and the cost of drilling the great number of closely spaced wells required for water-flooding operations, this is an important factor. While the method calls for a larger immediate investment, the total investment is smaller. Drilling all the wells on a particular tract at one time results in an appreciable saving in the cost per well. The installation of powers, rod lines, pipe lines, etc., is also considerably simplified. This work has to be done but once for the whole tract, while with old style methods, changes had to be made as the flood advanced. Also, in "circle" and "line" floods, with the exception of the original intake wells, all the wells subsequently drilled had to be tubed first to pump oil and later to take water, which meant an additional expense. There is also a large saving in operating costs, in that a tract is depleted much sooner.

The "five-spot" method has been adopted so recently that very few tracts on which it has been used have reached the economic limit of production. Many "five-spot" floods, however, are sufficiently far advanced to show a total yield per acre at least as great as has been obtained on adjacent or nearby tracts by the old methods, and, in most instances, considerably greater. In both the "circle" and "line" floods it frequently became necessary, or at least was deemed advisable in order to keep up production, to drill new wells and let the water into wells that were not completely watered out, in order not to delay the advance of the flood. While some of the remaining oil was recovered later perhaps, in the next row of wells, a large percentage undoubtedly was trapped and lost. This procedure is not necessary with the "five-spot." The wells can be pumped until the oil no longer pays for its recovery.

It was discovered early that many old wells did not give the results obtained from new ones, either when used as producers or as intakes, the reason undoubtedly being that as the oil approaches a producing well, due to release of pressure, paraffin tends to separate out and partly close the pores of the sand for a short distance back from the walls of the well. It is doubtful, therefore, whether wells that have been used as oil producers for three or four years make quite as satisfactory water intakes as wells expressly drilled for that purpose. In the five-spot flood, all the water intakes are new wells.

In practically all new development work arrangements are made to introduce the water at the top of the well and, in most instances, the wells are tubed in such a manner that pressure in addition to that of the hydrostatic head of the column in the well can be maintained. This has made it possible to determine by means of meters just how much water is entering the sand through each well. Formerly almost no data of this type were available and little was known about the behaviour of the intake wells. Each intake is now assured an adequate supply of water. Where properties are along the crests of sharp divides, it is now definitely known that, in many instances, the supply of subsurface water is inadequate during the dry months. Such properties, therefore, are now showing much better results where the five-spot method combined with pressure flooding has been introduced. Pressure flooding has also made it possible to flood areas of somewhat less permeable sand, which did not respond satisfactorily to former methods.

Mechanics of Water - Flooding

In fields of the Bradford type, where the potential energy of gas under pressure, including both gas dissolved in the oil and free gas, is practically the sole source of energy for expelling the oil from the sand, much oil remains in the sand after the pressure becomes so depleted that the wells can no longer be operated at a profit. As Bartell and Miller[79] have pointed out, such oil is held in the sand in two different ways. Part of it is mechanically held within the capillary pore spaces and small openings between the sand grains. That part of the pore space not occupied by liquid is filled with gas which was released from solution in the oil by the reduction in pressure and in part may have been present originally. Oil held in this manner will flow through the openings in the sand when under pressure. Another part of the oil occurs as an adsorbed film surrounding individual sand grains and is held so firmly that it is not removed by pressure-flow methods but remains on the sand. Very little definite information is as yet available in regard to the exact thickness of such films and the percentage of the total oil remaining in the sand that is present in this condition. As has been pointed out, a small amount of connate water probably also remains in the sand, adhering perhaps in part to the walls of the pores and in part filling the smallest of the capillary openings.

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[79] F. E. Bartell and F. L. Miller, Degree of wetting of silica by crude petroleum oils: Indus. and Eng. Chemistry, vol. 20, p. 738, 1928.

It is estimated that only about 16 percent of the oil originally present in the Bradford pool was recovered by the ordinary production methods. This low recovery was due to several causes. The relatively low permeability of the sand in larger parts of the field was an important factor. The lenticular nature of the individual sand layers that comprise the sand body was probably another. Little is known of the original reservoir pressure in the Bradford pool. In the nearby Ormsby pool pressures as high as 570 pounds per square inch were reported in the Bradford Third sand and 750 pounds in the Kane when that pool was opened. Inasmuch as the Bradford pool was developed long before the forces by which oil is expelled from a reservoir were understood, it is needless to say that the reservoir energy of the pool was not utilized to the best advantage.

Water-flooding under favorable conditions removes much of the oil mechanically held in the pores and probably also some of the adsorbed oil. Quartz sand and the clay minerals have a greater affinity for water than for oil.[80] The greater adhesion tension of water as compared to oil against silica makes water a good driving medium. Water has a tendency to replace oil in the small openings and force the oil into the larger ones. This may even result in water by-passing the oil. The water adheres primarily to the silica surfaces and the oil is left to occupy a space in the water tube or capillary. The oil adjusts itself to the large openings and is not easily dislodged, while the water moves around it until the rate of flow is increased to the point that the friction of the water against the oil surface exceeds the resisting force and the oil is crowded through the smaller openings to the outlet.[81]

Under certain conditions, however, according to Nutting,[82] quartz surfaces may have become activated so that oil coming in contact with them will not simply wet them but will be selectively adsorbed on them. Once such a surface has become covered with oil, it no longer has a greater affinity for water than for oil, but prefers oil to water. Water does not readily replace oil clinging to such adsorbed layers.

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[80] F. E. Bartell and F. L. Miller, idem. p. 741, 1928.
Allen D. Garrison, Selective wetting of reservoir rocks and its relation to oil production: Oil and Gas Jour., vol. 34, p. 36, August 15, 1935.

[81] Alex. W. McCoy and W. Ross Keyte, Present interpretation of the structural theory for oil and gas migration and accumulation: Problems of Petroleum Geology, Am. Assoc. Petroleum Geologists, p. 273, 1934.

[82] P. G. Nutting, Some physical and chemical properties of reservoir rocks bearing on the accumulation and discharge of oil: Problems of Petroleum Geology, Am. Assoc. Petroleum Geologists, pp. 830-832, 1934.

Uren and Fahmy[83] have discussed some of the factors that influence the recovery of petroleum by water-flooding as revealed by laboratory experiments with unconsolidated sands. They found that capillarity is not a controlling factor in the process of water-flooding; that flooding efficiency decreases markedly as the viscosity of the oil increases; that oils having the lower surface tensions can be more effectively displaced from sands by flooding than those of higher surface tension; that temperature influences efficiency, primarily on account of its effect on the viscosity and surface tension of the oil; that the efficiency of flooding increases as the interfacial tension of the oil against the flooding medium decreases; and that a slow rate of advance of the flooding medium through the oil sand results in greater recovery of oil than is possible by rapid displacement. Working with unconsolidated sands, they found that water-flooding was more effective in coarse-grained sands and in sands of high porosity than in fine-grained sands or sands of low porosity. This is contrary to actual operating experience in the Bradford and other eastern fields where water-flooding has been tried. The reason probably is that in the laboratory experiments as conducted much oil floated upward on the column of water as it rose vertically through the highly porous unconsolidated sand. Under actual field conditions, the movement is largely horizontal and by-passing, owing to differences in permeabilities of the various layers of sand, becomes the outstanding factor.

Laboratory experiments show that the flow of liquids through porous media follow Darcy's law, which states that the velocity of flow is proportional to the pressure gradient provided the flow is viscous, not turbulent in nature. The very slow movement of the liquids in a water flood is undoubtedly of the viscous type. Inasmuch as Darcy's law is equivalent to the law of electrical conduction, Wyckoff, Botset and Muskat[84] have made use of an electrolytic model to study pressure distribution and advance of the flood front, in which motion of the ions in the potential field is the same as the motion of the fluid particles in a fluid-sand model.

The model consisted of an electrolyte containing an ion indicator, such as phenolphthalein, held in a suitable porous medium to prevent excessive velocity of normal diffusion. The negative electrode in the model represented the input well and the positive terminal, the producing well. The advance of the hydroxyl ions from the negative to the positive electrode corresponds to the advancing fluid front. This advance of the hydroxyl ions is indicated by the color of the phenolphthalein indicator which is colorless in acid and red in the presence of hydroxyl ions. Photographs were taken showing various stages in the advance of the flood front, using different types of flood patterns.

Various stages in the advance of the flood front up to the time that it first reaches the output well for the five-spot and the seven-spot pattern are shown in Figure 39. It will be noted that during the early stages of the flood the advance is circular and it is only during the latter stages that a sharp cusp forms into the producing well. The models depict the flow through a sand of uniform thickness and uniform permeability throughout.

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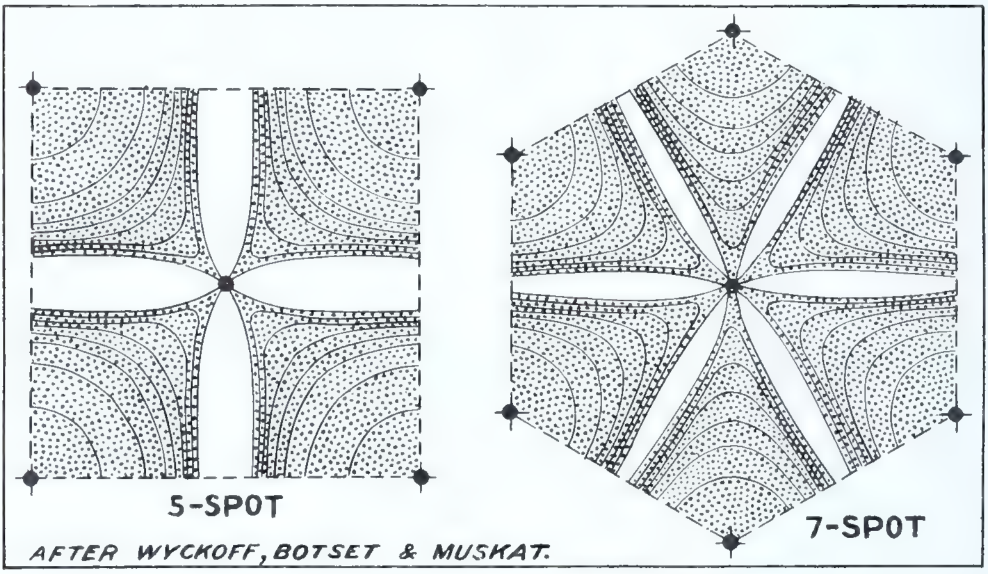
[83] L. C. Uren and E. H. Fahmy, Factors influencing the recovery of petroleum from unconsolidated sands by water-flooding: Petroleum Dev. and Tech., 1927, Trans. Am. Inst. Min. Eng., vol. 77, pp. 318-332, 1928.

[84] R. D. Wyckoff, H. G. Botset and M. Muskat, The mechanics of porous flow applied to water-flooding problems: Trans. Am. Inst. Min. Eng., vol. 103, pp. 219-240, 1933.

Three types of flood patterns are shown in Figure 40. The first or five-spot is the one most commonly used. Muskat and Wyckoff[85] find that under ideal conditions this pattern gives an efficiency of 72.3 percent, that is, this percent of the area will have been flooded out by the time the water reaches the output well.

This figure must not be taken too literally, however. It applies to ideal conditions. The Bradford Third sand, instead of being a single bed of uniform sandstone, is usually a whole series of individual layers, each one of which may possess a different porosity, permeability, oil and gas content, etc. The flood front, therefore, will not reach the producing well at the same time for all the layers and hence the first appearance of water in actual field practice does not necessarily mean that 72.3 percent of the entire volume of the sand body has been flooded out. By-passing of water along the more permeable layers may become so great that the economic limit of production will be reached long before 72.3 percent of all the layers have been flooded out. Under particularly favorable conditions, on the other hand, it may be possible to operate the producing well beyond the 72.3 percent stage. Lateral variations in the sand will also alter the ideal shape of the advancing flood. Figure 40 is of value for comparing patterns, which is its purpose. It must also be kept in mind that because 72.3 percent of the sand has been flooded does not mean that 72.3 percent of the oil in it has been recovered. Much of the oil may be under such conditions that water-flooding will not remove it.



AFTER WYCKOFF, BOTSET & MUSKAT.

FIGURE 39. Various stages in the advance of the flood front in a 5-spot and 7-spot pattern as shown by electrolytic models

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[85] M. Muskat and R. D. Wyckoff, A theoretical analysis of water-flooding networks: Trans. Am. Inst. Min. Eng., vol. 107, p. 72, 1934.

Five-spot pressure floods in actual operation are spaced all the way from 215 to 320 feet on a side, making the distance between intake and producing wells 152 to 226 feet. In order to reduce development costs there has been a tendency in recent years to increase the distance between wells, but in relatively few instances has the distance between input wells been made greater than 320 feet.

The seven-spot pattern has been used but little. It is more dufficult to adjust to the boundaries of a particular tract than the five-spot. According to Muskat and Wyckoff, this pattern has an efficiency of 74.0 percent, as compared to 72.3 percent for the five-spot. In order to have the same well-per-acre density with this pattern as with the five-spot, it is necessary to make the distance between water-input and oil well 1.074 times as great as in the five-spot. The relative production rate then becomes about 13 percent less than that of the five-spot.

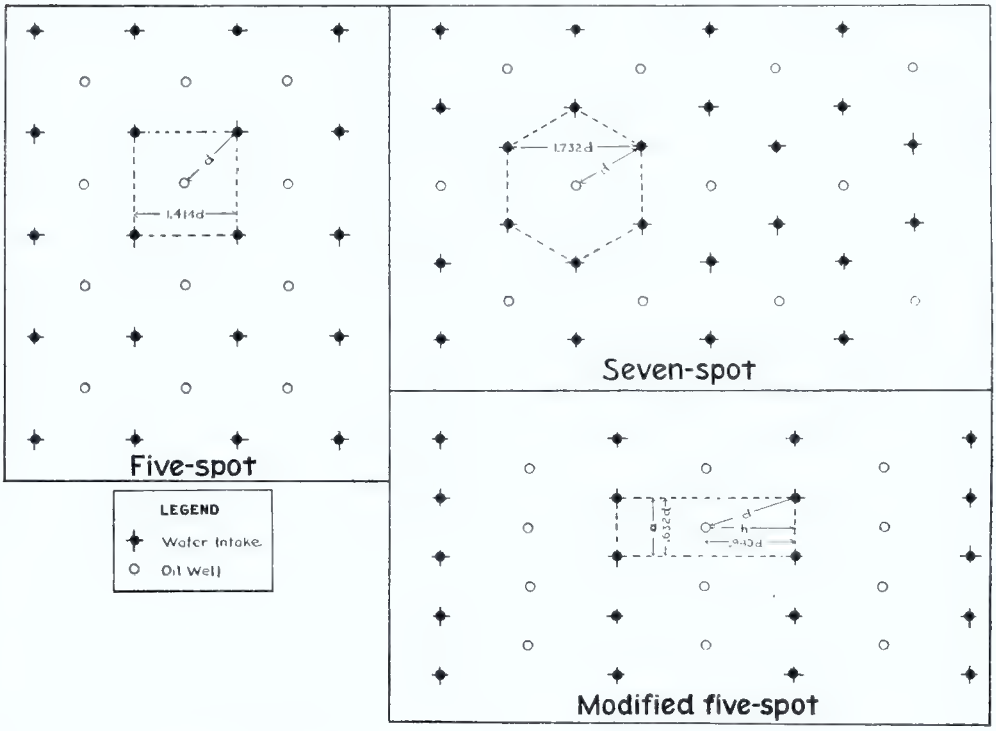

FIGURE 40. Various types of intensive flood patterns.

The modified form of five-spot in Figure 40, when the ratio of h to a is equal to 1.5:1, has an efficiency of 80 percent. With a distance between water-input and oil well 1.291 times that of the five-spot, in order to make the well-per-acre density the same, its relative production rate is about 12 percent less than that of the five-spot.[86] Some operators have modified the regular five-spot pattern by lengthening it in one direction and shortening it in the other in order to make it fit a particular tract, but as far as the writer knows, not to such an extent as to have the ratio h to a = 1.5:1.

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[86] M. Muskat and R. D. Wyckoff, idem.

One of the most difficult conditions in parts of the Bradford pool is the occurrence of alternate layers of sand that differ greatly in permeability. This is well illustrated by the permeability profile of core 18, shown in Plate 18. One of the means of overcoming this condition, at least partly, in pressure flooding is to delay drilling the oil wells until after the water under pressure has had 4 to 6 months, or even longer, to enter the sand, the time depending on conditions shown by core analyses of the sand and the time normally required for the oil wells to reach a peak if drilled at the same time as the intake wells. At first the water tends to enter the more permeable layers rapidly, crowding the little globules of oil and bubbles of gas ahead of it as the volume of the gas shrinks. As the pressure builds up, part of the gas also goes into solution in the oil. Finally, since there is no outlet until the oil well is completed, such a pressure is built up ahead of the advancing flood of water that no further movement is possible. In the meantime, water also enters the less permeable layers, but at a slower rate, and by delaying the drilling of the oil wells a considerable advance in these layers also takes place; but of course, on account of the smaller size of the openings, equilibrium is established and conditions become static with the front of the flood at a shorter distance from the intake well. When the oil well finally is drilled, there has already been built up a bank of oil under pressure ahead of the water which commences to move toward the well.

If the oil well is completed and put on production when the water under pressure is applied to the intake well, the water travels through the more permeable layers comparatively rapidly, and once it reaches the oil well, with the resistance due to the presence of the gas bubbles overcome, the velocity becomes dependent on the pressure applied, as the flow of water through the sand thereafter probably closely follows the law of flow of water through capillary tubes; that is, the lineal velocity varies directly as the difference in pressure at the face of the sand in the intake and producing wells.

If the pressure at the face of the sand in the intake well is kept constant by supplying all the water that it will take at that pressure, the water eventually will pass through the less permeable layers also, provided the pressure is great enough to cause a perceptible movement from the intake to the producing well through such layers. However, enormous quantities of water that are by-passing through the more permeable layers will have to be handled in order to recover relatively small volumes of oil from the less permeable ones. In delayed drilling, a greater part of the work necessary to move oil from the intake toward the producing well is accomplished before this by-passing occurs; hence more oil is recovered with a smaller volume of water. In carrying out a delayed-drilling program, all old wells must be carefully plugged off at the top of the sand.

Delayed drilling is being practiced by several operators in the Bradford district. The oil wells are drilled anywhere from 6 to 18 months after the water has been turned in on the sand, this being about the time that is required on their tracts for the producing wells to reach their peak in oil production when drilled at the same time as the intake wells. In the examples of this procedure that have come to the writer's attention, the oil production has been either equal to or greater than when the two sets of wells were drilled simultaneously. In some cases the water output to oil ratio for the entire period of production has been appreciably reduced.

By eliminating the early period of small production, a saving is made in interest charges and in pumping costs. Some operators have observed, however, that if the drilling of the oil wells is delayed too long, the wells commence producing a large volume of water before the expected quantity of oil has been obtained. This perhaps is due to the fact that the permeability of the sand varies horizontally as well as vertically and as a result the bank of oil that is built up ahead of the water does not develop symmetrically around the center of the pattern. By installing meters at each intake well and regulating the flow of water, this can perhaps be controlled to a certain extent. At best, however, delayed drilling affords only a partial solution of the by-passing problem.

Production Data for Various Types of Floods

Examples of different types of flood patterns and methods of applying the water-drive in various parts of the Bradford field have been selected and records of their production history compiled. Some circle and line floods have been included for comparison. The circle floods are fairly representative of what were considered successful operations by this method in various parts of the field. The data on line floods are not so complete and perhaps are not representative of the best results obtained from the standpoint of yield per acre. The examples of intensive floods, on the other hand, are believed to be typical of the results now being obtained by water-flooding in the Bradford district. Various sand conditions are represented. The approximate locations of the properties from which the examples are taken are shown on Plate E.

Circle Floods

Flood No. 1

Flood No. 1 represents a circle flood in the northeast part of the Bradford pool near Red Rock. The extent of the flood is shown on Figure 41. An area of 11.4 acres had been watered out by a previous operator when the keeping of records of the oil and water output of individual wells started. During the succeeding 13 years the flood front advanced about 450 feet on the north side, an average of 35 feet per year, and 400 feet on the south side, an average of 31 feet per year.

The 17.8 acres watered out on the north side during that period yielded 144,521 barrels of oil, or an average of 8,119 barrels per acre. Only half of the total production of wells E and F is included in the above amount because these two wells also had water intake wells north of them along the property line. The sand body in this area, as shown by the drillers' records, averages 47 feet thick. Assuming that 67 percent of this is oil-bearing sandstone gives a thickness of 31 feet, which makes the yield 262 barrels per acre-foot. The top of the sand in this area occurs at an average depth of 1,410 feet, so that the maximum pressure possible by hydrostatic head was 600 pounds per square inch, as only subsurface water entered the intake wells.

The 6.7 acres watered out on the south side during the same period yielded 58,329 barrels, or an average of 8,706 barrels per acre. The thickness of the sand body in this area averages 41 feet and oil-bearing sandstone about 27 feet, making the yield 322 barrels per acre-foot. The top of the sand occurs at an average depth of 1,480 feet, so that the maximum pressure possible was 640 pounds per square inch.

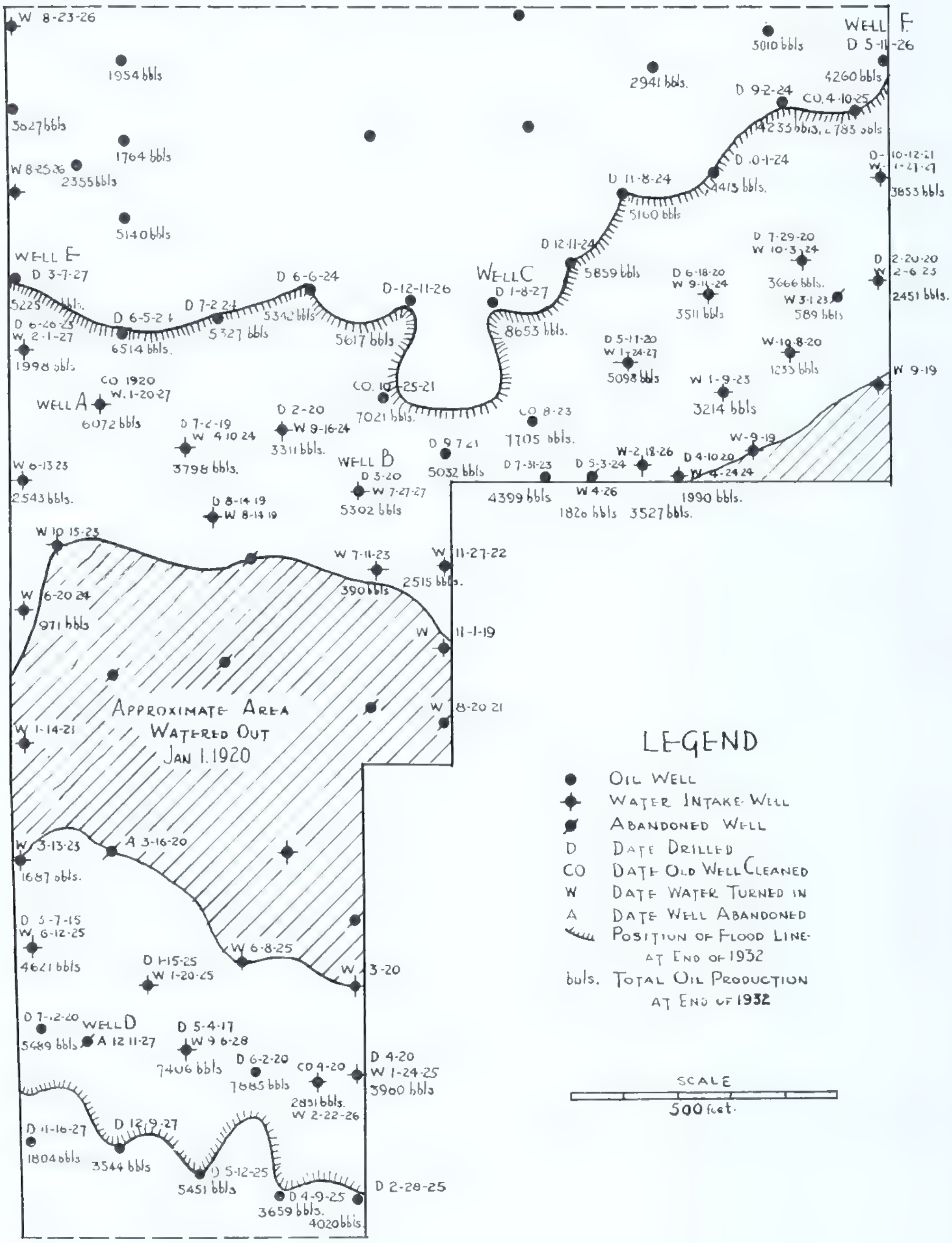

FIGURE 41. **Map of Flood No. 1.**

It is probable that some oil from the area that was watered out prior to January 1, 1920, was pushed over into the two areas included in the above estimate. If an allowance were made for this, the above figures, of course, would be reduced somewhat. However, even if the entire 11.4 acres be added to that of the above two areas, on the assumption that the previous owners had recovered practically none of the flood oil, the average yield per acre would still be 5,623 barrels, or 187 barrels per acre-foot of oil-bearing sandstone.

The average daily and cumulative oil and water production of two wells in Flood No. 1 by months are given in Table 68 and their average daily production is shown graphically in Figure 42. Well A was an old well which was cleaned out. The water was shut off permanently from all intake wells in this flood in June, 1931. It is interesting to note the immediate effect that this had upon the performance of well C. The break in the curve of this well during 1930 was due to curtailment of production in connection with proration. This was accomplished by reducing the pumping from twice a day to two or three times a week. The average daily oil production per well by years is given in Table 69 and the water output to oil ratios for four of the wells is shown in Table 70.

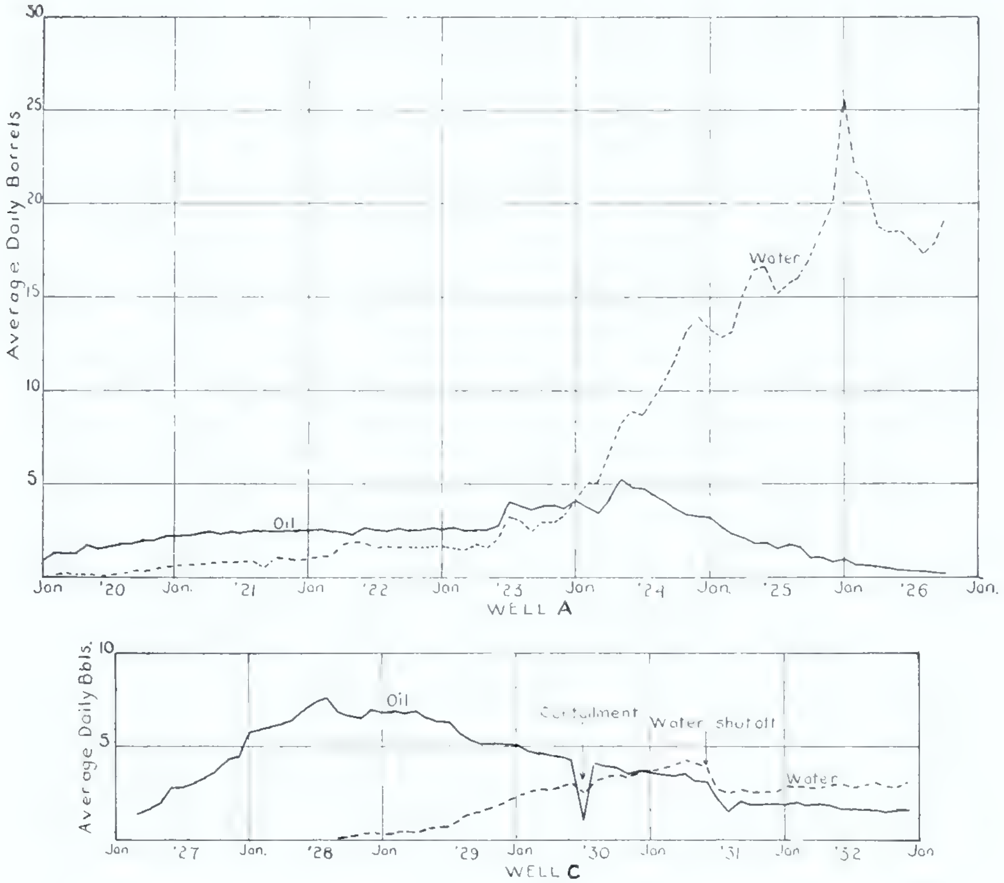

FIGURE 42. **Curves showing average daily production of oil and water by months for two wells in Flood No. 1.**

Table 68. Average daily and cumulative oil and water production of two wells in Flood No. 1 by months, in barrels.

Well A

Date	Oil Production Avge. Daily	Oil Production Cumulative	Water Production Avge. Daily	Water Production Cumulative
1920				
Jan.	.88	27	.00	0
Feb.	1.34	66	.14	4
Mar.	1.23	94	.24	12
Apr.	1.25	132	.16	16
May	1.79	187	.14	21
June	1.57	234	.07	23
July	1.68	286	.09	26
Aug.	1.82	343	.18	31
Sept.	1.82	397	.32	41
Oct.	2.01	460	.34	51
Nov.	1.97	519	.44	64
Dec.	2.11	584	.51	80
1921				
Jan.	2.13	650	.61	99
Feb.	2.13	711	.62	117
Mar.	2.16	778	.70	139
Apr.	2.42	851	.70	160
May	2.31	922	.80	184
June	2.45	996	.78	208
July	2.42	1071	.81	233
Aug.	2.52	1149	.85	259
Sept.	2.43	1222	.55	276
Oct.	2.46	1298	1.07	309
Nov.	2.50	1373	1.04	340
Dec.	2.51	1451	.98	370
1922				
Jan.	2.51	1529	1.04	403
Feb.	2.59	1601	1.12	434
Mar.	2.49	1678	1.13	469
Apr.	2.45	1752	1.79	523
May	2.23	1821	1.86	580
June	2.66	1901	1.89	637
July	2.58	1981	1.60	687
Aug.	2.55	2060	1.71	740
Sept.	2.61	2138	1.63	789
Oct.	2.54	2217	1.65	840
Nov.	2.52	2292	1.60	888
Dec.	2.63	2375	1.61	938
1923				
Jan.	2.59	2453	1.64	989
Feb.	2.68	2528	1.61	1,034
Mar.	2.50	2606	1.51	1,080
Apr.	2.55	2682	1.78	1,134
May	2.52	2760	1.73	1,187
June	2.74	2843	2.11	1,251
July	4.03	2967	3.37	1,355
Aug.	3.86	3087	3.16	1,453
Sept.	3.68	3198	2.48	1,528
Oct.	3.87	3317	2.98	1,620
Nov.	3.91	3435	3.02	1,711
Dec.	3.61	3546	3.28	1,812
1924				
Jan.	4.12	3674	4.13	1,940
Feb.	3.78	3784	5.03	2,086
Mar.	3.46	3891	5.11	2,245
Apr.	4.16	4016	6.79	2,448
May	5.38	4182	8.21	2,703
June	4.91	4330	8.94	2,971
July	4.80	4479	8.64	3,240
Aug.	4.43	4616	9.68	3,540
Sept.	4.07	4738	10.54	3,857
Oct.	3.71	4853	11.85	4,224
Nov.	3.32	4953	13.33	4,624
Dec.	3.31	5055	13.91	5,055
1925				
Jan.	3.22	5155	13.22	5,465
Feb.	2.68	5230	12.88	5,826
Mar.	2.28	5301	13.14	6,234
Apr.	2.08	5363	15.17	6,688
May	1.81	5419	16.47	7,199
June	1.86	5475	16.66	7,698
July	1.58	5524	15.23	8,171
Aug.	1.78	5579	15.78	8,660
Sept.	1.62	5628	16.06	9,141
Oct.	1.00	5659	17.38	9,680
Nov.	1.12	5692	18.67	10,240
Dec.	.82	5718	19.84	10,855
1926				
Jan.	1.00	5749	25.60	11,649
Feb.	.72	5769	21.67	12,256
Mar.	.68	5790	21.28	12,915
Apr.	.62	5809	18.83	13,480
May	.44	5822	18.46	14,053
June	.36	5833	18.53	14,604
July	.35	5844	18.04	15,163
Aug.	.31	5854	17.25	15,697
Sept.	.25	5861	17.82	16,232
Oct.	.19	5867	19.29	16,830

Well C

1927				
Mar.	1.43	44	.01	0
Apr.	1.63	92	.03	1
May	1.89	149	.12	5
June	2.82	234	.13	9
July	2.88	323	.12	13
Aug.	3.09	419	.14	17
Sept.	3.39	520	.15	21
Oct.	3.70	635	.25	29
Nov.	4.34	765	.06	31
Dec.	4.52	905	.11	34
1928				
Jan.	5.91	1089	.00	34
Feb.	5.98	1262	.00	34
Mar.	6.15	1453	.00	34
Apr.	6.30	1642	.00	34
May.	6.53	1844	.00	34
June	7.04	2055	.00	34
July	7.43	2286	.00	34
Aug.	7.60	2521	.00	34
Sept.	6.85	2727	.17	39
Oct.	6.75	2936	.18	45
Nov.	6.59	3134	.26	58
Dec.	7.01	3351	.40	65
1929				
Jan.	6.88	3564	.36	76
Feb.	6.89	3751	.42	88
Mar.	6.82	3963	.51	104
Apr.	6.88	4169	.44	117
May	6.53	4371	.60	136
June	6.35	4562	.70	157
July	6.36	4759	.77	181
Aug.	5.73	4937	1.21	218
Sept.	5.36	5097	1.47	262
Oct.	5.13	5256	1.57	311
Nov.	5.18	5412	1.76	364
Dec.	5.17	5572	2.06	428
1930				
Jan.	5.08	5730	2.32	499
Feb.	4.80	5864	2.46	568
Mar.	4.62	6007	2.68	651
Apr.	4.52	6143	2.72	733
May	4.44	6281	2.88	822
June	4.34	6411	3.10	915
July	1.01	6442	2.46	992
Aug.	4.14	6570	3.20	1,092
Sept.	3.97	6689	3.40	1,193
Oct.	3.91	6807	3.48	1,301

Table 68 (Continued)

Well C (Continued)

Date	Oil Production Avge. Daily	Oil Production Cumulative	Water Production Avge. Daily	Water Production Cumulative
Nov.	3.54	6913	3.37	1,402
Dec.	3.72	7028	3.71	1,517
1931				
Jan.	3.60	7140	3.68	1,631
Feb.	3.48	7237	3.85	1,735
Mar.	3.43	7343	4.04	1,861
Apr.	3.58	7451	4.28	1,989
May	3.19	7550	4.16	2,118
June	3.06	7642	3.97	2,237
July	2.18	7709	2.74	2,322
Aug.	1.48	7771	2.56	2,401
Sept.	2.09	7833	2.67	2,482
Oct.	1.94	7894	2.61	2,562
Nov.	1.92	7951	2.62	2,641
Dec.	1.99	8013	2.65	2,723
1932				
Jan.	1.91	8072	2.89	2,813
Feb.	2.04	8131	2.97	2,899
Mar.	1.86	8189	2.91	2,999
Apr.	1.97	8248	2.82	3,074
May	1.83	8305	2.96	3,166
June	1.70	8356	3.03	3,256
July	1.71	8409	2.84	3,344
Aug.	1.66	8460	2.92	3,435
Sept.	1.65	8510	3.07	3,527
Oct.	1.57	8558	2.91	3,617
Nov.	1.60	8606	2.86	3,703
Dec.	1.63	8657	3.15	3,801
1933				
Jan.	1.63	8707	3.11	3,897
Feb.	1.62	8753	3.17	3,986
Mar.	1.65	8804	3.06	4,081
Apr.	1.51	8849	3.08	4,173
May	1.52	8896	3.02	4,237
June	1.37	8937	3.30	4,336
July	1.62	8988	3.56	4,446

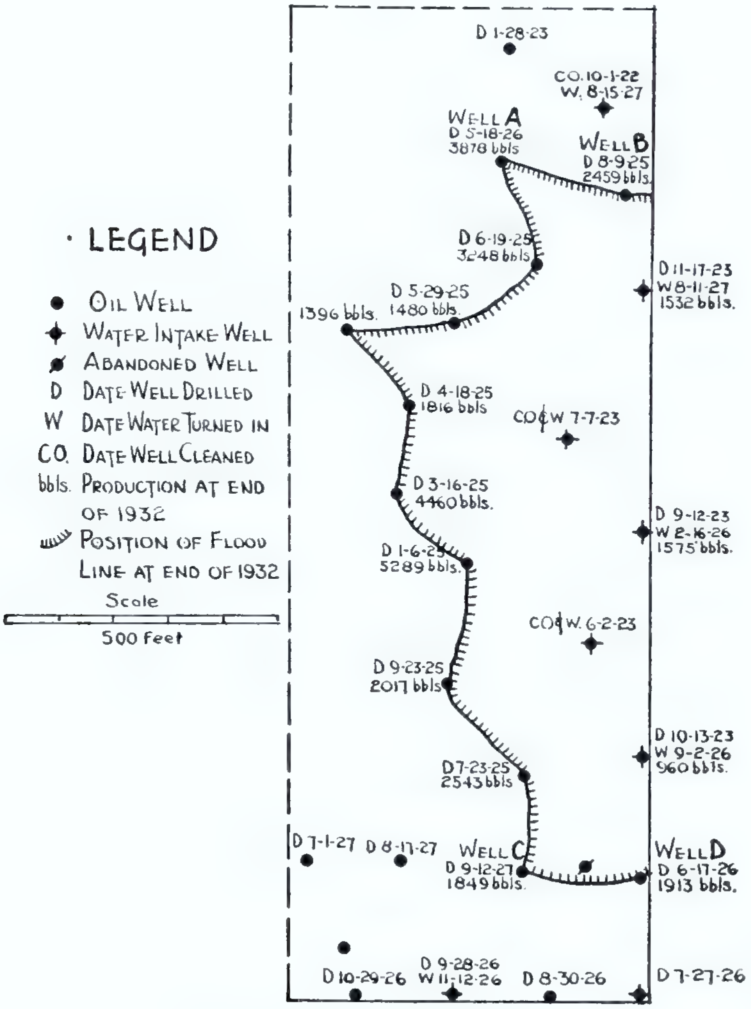

FIGURE 43. Map of Flood No. 2.

Table 69. Average daily oil production per well for Flood No. 1 by years

North side						South side					
Year	Wells	Bbls.	Year	Wells	Bbls.	Year	Wells	Bbls.	Year	Wells	Bbls.
1920	17	2.49	1927	20	2.43	1920	8	3.36	1937	9	1.30
1921	19	1.72	1928	16	2.39	1921	8	2.59	1928	8	1.71
1922	19	1.32	1929	16	1.60	1922	8	1.70	1929	7	1.87
1923	18	1.32	1930	16	1.09	1923	8	1.17	1930	7	1.02
1924	22	1.52	1931	16	.77	1924	6	1.24	1931	7	.35
1925	18	2.49	1932	16	.55	1925	9	1.58	1932	7	.25
1926	20	2.12				1926	7	2.43			

Table 70. Water output to oil ratios of four wells in Flood No. 1

Well	Total oil production bbls.	Total water output, bbls.	Water output to oil ratio
A	5,867	16,830	2.87:1
B	5,343	20,651	3.86:1
C	8,988	4,446	.49:1
D	5,848	21,060	3.60:1
Total	26,046	62,987	2.42:1

Flood No. 2

Flood No. 2 is a circle flood in the northeastern part of the Bradford pool southeast of Derrick City. The extent of the flood is shown on Figure 43. The flood was started in June 1923. At the end of 9½ years, 9.7 acres had been watered out.

The flooded area yielded 36,418 barrels of oil, or an average of 3,754 barrels per acre. Only one-half of the total production of wells A, B, and D and one-third of that of well C are included in the above amount since these four wells also had a water-drive acting on them that came from intake wells outside the area included in this flood. The sand body, as shown by the drillers' records, averages 41 feet thick. Assuming that 64 percent of this is oil-bearing, then 26 feet of actual sandstone yielded 144 barrels per acre foot. The top of the sand occurs at an average depth of 1378 feet, so that the maximum pressure possible by hydrostatic head was 600 pounds per square inch, inasmuch as only subsurface water entered the intake wells.

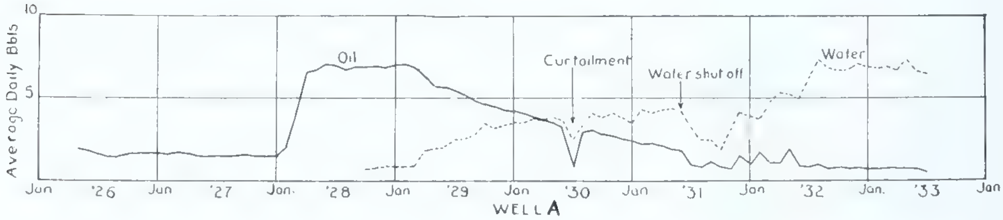

FIGURE 44. **Curve showing average daily production of oil and water by months for well A in Flood No. 2.**

The average daily and cumulative oil and water production of one well in Flood No. 2 by months are given in Table 71 and the average daily production is shown graphically in Figure 44. The break in the curve of this well during 1930 was due to curtailment of production. This was accomplished by reducing the pumping from twice a day to two or three times a week. The water was shut off permanently from all intake wells in June 1931.

Table 71. Average daily and cumulative oil and water production of well A in Flood No. 2 by months, in barrels

	Oil Production		Water Production	
Date	Avge. Daily	Cumulative	Avge. Daily	Cumulative
1926				
May	1.86	58		
June	1.83	113		
July	1.75	167		
Aug.	1.55	214		
Sept.	1.57	261		
Oct.	1.62	311		
Nov.	1.68	362		
Dec.	1.67	413		
1927				
Jan.	1.67	465		
Feb.	1.60	509		
Mar.	1.74	564		
Apr.	1.69	615		
May	1.52	662		
June	1.46	705		
July	1.53	753		
Aug.	1.53	800		
Sept.	1.55	847		
Oct.	1.59	896		
Nov.	1.70	947		
Dec.	1.69	999		
1928				
Jan.	1.70	1052		
Feb.	2.01	1111		
Mar.	4.04	1236		
Apr.	6.53	1432		
May	6.69	1639		
June	7.07	1851		
July	6.98	2068		
Aug.	6.65	2274		
Sept.	6.85	2479	.06	2
Oct.	6.92	2694	.67	23
Nov.	6.94	2902	.76	45
Dec.	6.85	3114	.91	74
1929				
Jan.	7.01	3332	.92	102
Feb.	7.03	3528	.89	127
Mar.	6.86	3741	.92	156
Apr.	6.36	3932	1.81	210
May	5.78	4111	1.96	271
June	5.72	4282	2.05	332
July	5.54	4454	2.49	409
Aug.	5.24	4617	2.53	458
Sept.	4.92	4764	2.81	542
Oct.	4.69	4909	3.46	637
Nov.	4.54	5046	3.20	733
Dec.	4.29	5178	3.34	836
1930				
Jan.	4.24	5309	3.50	945
Feb.	4.07	5424	3.52	1,044
Mar.	3.87	5514	3.77	1,130
Apr.	3.77	5595	3.71	1,212
May	3.55	5707	3.83	1,330
June	3.20	5803	3.63	1,439
July	.82	5828	2.42	1,514
Aug.	2.96	5920	3.47	1,622
Sept.	3.06	6012	4.05	1,743
Oct.	2.83	6099	3.82	1,832
Nov.	2.76	6182	4.11	1,955
Dec.	2.51	6260	3.85	2,044
1931				
Jan.	2.47	6337	3.42	2,151
Feb.	2.22	6399	4.38	2,273
Mar.	2.24	6468	4.16	2,402
Apr.	2.13	6532	4.30	2,531
May	1.98	6594	4.35	2,666
June	1.88	6650	4.23	2,793
July	.98	6680	3.26	2,895
Aug.	.84	6707	2.49	2,972
Sept.	1.19	6742	2.46	3,046
Oct.	.85	6769	1.80	3,101
Nov.	.71	6799	2.97	3,168
Dec.	1.42	6834	4.14	3,297
1932				
Jan.	.98	6864	3.88	3,387
Feb.	1.77	6916	3.65	3,485
Mar.	1.06	6958	4.76	3,632
Apr.	1.06	6990	5.38	3,794
May	1.95	7029	5.26	3,957
June	.84	7045	4.92	4,104
July	.83	7071	6.11	4,294
Aug.	.91	7099	7.35	4,522
Sept.	.69	7129	6.85	4,727
Oct.	.74	7143	6.70	4,935
Nov.	.73	7164	6.78	5,138
Dec.	.73	7187	7.13	5,359
1933				
Jan.	.64	7207	6.92	5,572
Feb.	.65	7225	6.85	5,764
Mar.	.69	7246	6.97	5,980
Apr.	.65	7265	6.76	6,182
May	.67	7287	7.35	6,410
June	.63	7306	6.66	6,610
July	.41	7318	6.39	6,808

Flood No. 3

Flood No. 3 is a circle flood in the northeastern part of the Bradford pool along Indian Creek. The extent of the flood is shown on Figure 45. It came onto the property from the northeast in 1913 and during the succeeding 16½ years watered out 21.8 acres.

The flooded area yielded 112,811 barrels of oil or an average of 5,175 barrels per acre. The sand body in this area, as shown by the drillers' record, averages 33 feet thick. Assuming that 73 percent, or 24 feet, is oil-bearing sandstone, makes the yield 216 barrels per acre-foot. The top of the sand occurs at an average depth of 1,130 feet, so that the maximum pressure possible by hydrostatic head was 490 pounds per square inch, inasmuch as only subsurface water entered the intake wells. The average daily oil production per well for Flood No. 3 by years is given in Table 72.

Table 72. Average daily oil production per well for Flood No. 3 by years

Year	Wells producing	Oil per well, bbls.	Year	Wells producing	Oil per well, bbls.	Year	Wells producing	Oil per well, bbls.
1913	7	.73	1919	16	2.25	1925	21	1.71
1914	10	1.25	1920	18	2.10	1926	20	1.48
1915	10	.88	1921	18	1.76	1927	20	.96
1916	13	.85	1922	18	.89	1928	27	1.51
1917	10	1.76	1923	21	.94	1929	21	1.27
1918	11	1.75	1924	18	1.21			

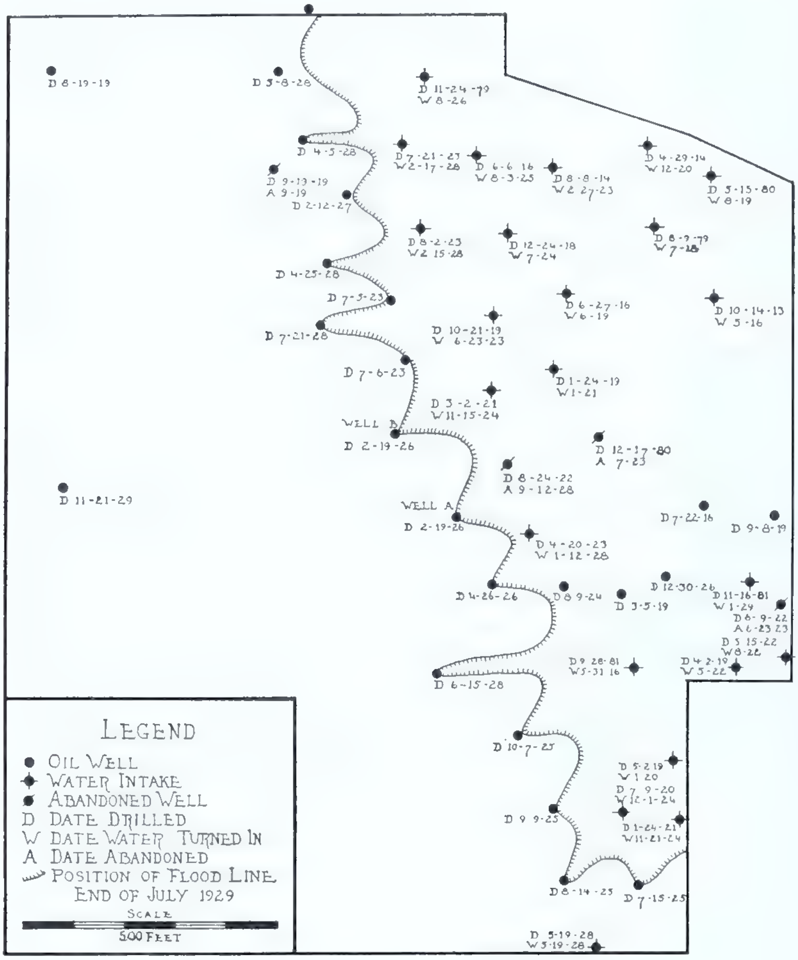

FIGURE 45. Map of Flood No. 3.

Flood No. 4

Flood No. 4 is an example of the circle type of water-flooding in the northeastern part of the Bradford pool along Fourmile Creek in the Town of Allegany, Cattaraugus County, New York. The extent of the flooded area is shown on Figure 46. A flood came onto the western part of the property from the south in July 1917. Another one was started that year in the center of the eastern part. The tract contains 37 acres. It was originally developed by eight wells which yielded 42,232 barrels of oil, or 1,141 barrels per acre, by ordinary production methods.

During 16 years, 30.7 acres were watered out. A total of 101,133 barrels of oil, or an average of 3,294 barrels per acre, was obtained in this operation. The sand body, as shown by the drillers' records, averages 50 feet thick. Assuming that 47 percent is oil-bearing, then 24 feet of actual sandstone yielded 137 barrels per acre-foot. The top of the sand occurs at an average depth of 1,347 feet, so that the maximum pressure possible by hydrostatic head was 585 pounds per square inch, inasmuch as only subsurface water entered the intake wells. The average daily oil production per well for the flood by years is given in Table 73.

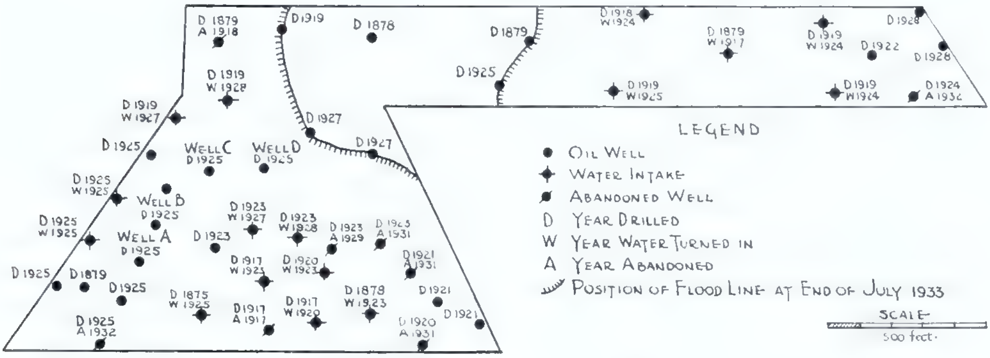

FIGURE 46. Map of Flood No. 4.

Table 73. Average daily oil production per well for Flood No. 4 by years

Year	Wells producing	Oil per well, bbls.	Year	Wells producing	Oil per well, bbls.	Year	Wells producing	Oil per well, bbls.
1913	8	.09	1920	17	.96	1927	27	1.46
1914	8	.12	1921	18	.83	1928	29	1.06
1915	8	.11	1922	19	.53	1929	27	.92
1916	8	.10	1923	21	1.06	1930	26	**.53
1917*	11	.14	1924	22	.64	1931	26	**.33
1918	10	.46	1925	30	1.16	1932	23	.49
1919	15	.86	1926	26	1.58	1933	21	.35

*Flood started in July.
**Production curtailed.

Flood No. 5

Flood No. 5 is an example of the circle type of operating in the northwestern lobe of the Bradford pool in the vicinity of Custer City. The extent of the watered-out area is shown on Figure 47. Floods originally came onto the northern part of this property both on the east and west sides during 1917 and 1918.

During 17 to 18 years, 12.3 acres were watered out. A total of 56,808 barrels of oil, or an average of 4,619 barrels per acre, was obtained in this operation. The sand body, as shown by drillers' records, averages 38 feet thick. Assuming that 74 percent is oil-bearing gives 28 feet of sandstone, which makes the yield 165 barrels per acre-foot. The top of the sand occurs at an average depth of 1,215 feet, so that the maximum pressure possible by hydrostatic head was 525 pounds per square inch, inasmuch as only subsurface water entered the intake wells. The average daily oil production per well prior to and after flooding started is given in Table 74.

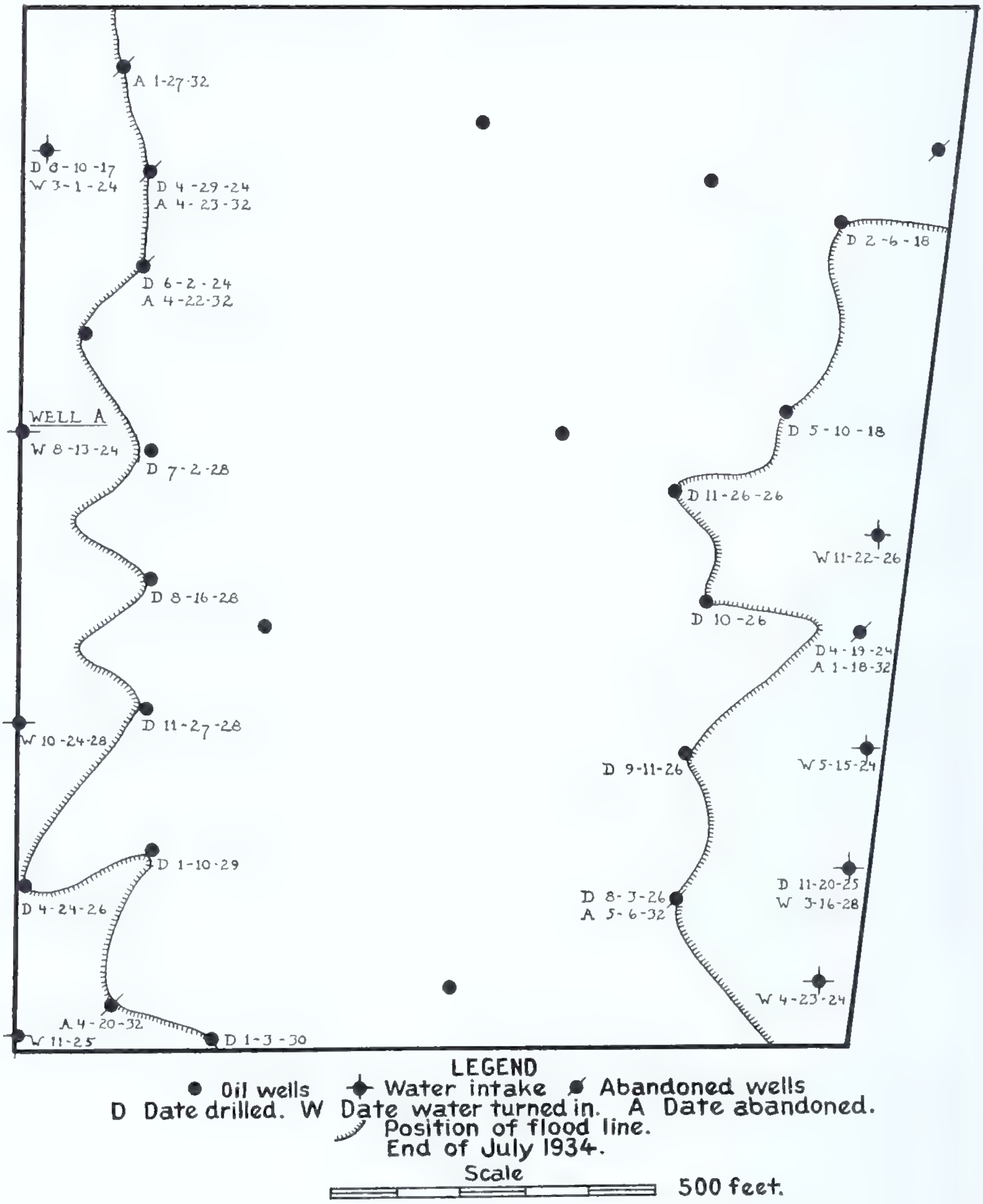

FIGURE 47. Map of Flood No. 5.

Table 74. Average daily oil production per well for Flood No. 5 by years.

Before water-flooding started			After water-flooding started		
Year	Wells producing	Oil per well Bbls.	Year	Wells producing	Oil per well Bbls.
1893	10	.59	1915	10	.14
1894	10	.49	1916	10	.19
1895	10	.40	1917	10.4	.36
1896	10	.33	1918	12.6	.46
1897	10	.32	1919	13.0	.41
1898	10	.27	1920	13.0	.41
1899	10	.24	1921	13.0	.33
1900	10	.27	1922	13.0	.36
1901	10	.42	1923	13.0	.48
1902	10	.36	1924	14.1	.48
1903	10	.31	1925	14.1	.66
1904	10	.33	1926	16.6	.96
1905	10	.28	1927	19.0	1.05
1906	10	.28	1928	19.2	.93
1907	10	.25	1929	22.0	.65
1908	10	.25	1930	23.0	.44
1909	10	.21	1931	23.0	.23*
1910	10	.19	1932	18.5	.35*
1911	10	.16	1933	16.5	.63
1912	10	.16	1934	16.0	.55
1913	10	.17			
1914	10	.16			

*Production curtailed.

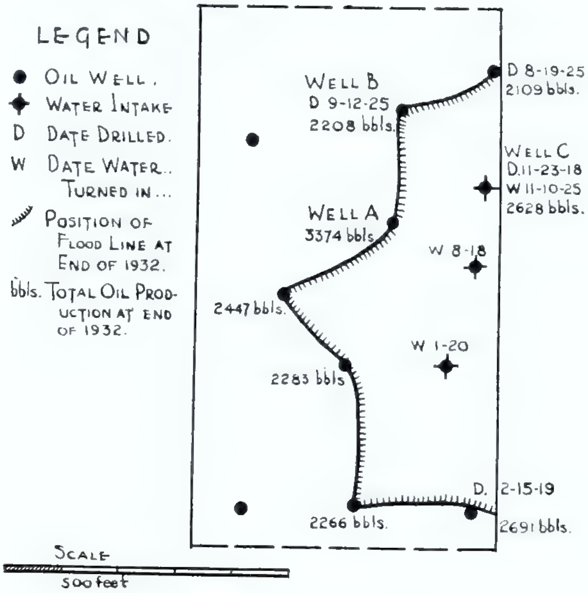

FIGURE 48. **Map of Flood No. 6.**

Flood No. 6

Flood No. 6, shown on Figure 48, is a small circle flood in the northwestern lobe of the Bradford pool along Sheppard Run west of Custer City. The flood was started in 1918 from a single well. In 15 years only 4.0 acres were watered out.

The flooded area yielded 20,053 barrels of oil, or an average of 5,013 barrels per acre. The sand body, as shown by the drillers' records, averages 58 feet thick. Assuming that 74 percent of this is oil-bearing, gives 43 feet of actual sandstone and a yield of 117 barrels per acre-foot. The top of the sand occurs at an average depth of 1,280 feet, so that the maximum pressure by hydrostatic head was 555 pounds per square inch, inasmuch as only subsurface water was used.

The water output to oil ratios for two of the wells for their entire production period are given in Table 75, and the average daily and cumulative oil and water production of one of them by months in Table 76. The latter is shown graphically in Figure 49.

Table 75. Water output to oil ratios of two wells in Flood No. 6

Well	Oil production Barrels	Water output Barrels	Water output to oil ratio
A	3,376	21,309	6.31:1
B	2,213	4,237	1.91:1
Total	5,589	25,546	4.57:1

Table 76. Average daily and cumulative oil and water production of well B in Flood No. 6 by months, in barrels

	Oil production		Water production	
Date	Avge. Daily	Cumulative	Avge. Daily	Cumulative
1925				
Sept.	1.79	54		
Oct.	1.33	95		
Nov.	1.51	140		
Dec.	1.69	193	.07	
1926				
Jan.	1.64	243	.10	3
Feb.	1.56	287	.16	8
Mar.	1.58	336	.11	11
Apr.	1.51	381	.16	16
May	1.12	416	.22	23
June	1.43	459	.43	36
July	1.22	497	.44	49
Aug.	1.17	533	.68	70
Sept.	1.16	568	.53	86
Oct.	1.16	604	.58	104
Nov.	1.22	637	.56	121
Dec.	1.19	674	.56	138
1927				
Jan.	1.45	719	.52	154
Feb.	1.36	757	.57	170
Mar.	1.15	793	.53	187
Apr.	1.18	828	.90	214
May	1.12	863	.85	240
June	1.12	897	.78	264
July	1.01	928	.66	284
Aug.	1.06	961	.69	306
Sept.	.97	990	.89	332
Oct.	1.00	1021	.67	352
Nov.	1.04	1052	.72	374
Dec.	.97	1082	.96	404
1928				
Jan.	1.00	1113	.82	429
Feb.	1.00	1142	.87	454
Mar.	1.04	1174	1.04	487
Apr.	.83	1199	.91	514
May	1.05	1232	1.11	548
June	.99	1262	.98	578
July	.93	1290	1.05	610
Aug.	1.01	1321	1.07	644
Sept.	.89	1348	1.51	689
Oct.	1.14	1383	2.11	754
Nov.	1.09	1416	2.11	818
1929				
Dec.	1.05	1449	2.01	880
Jan.	1.07	1482	2.09	945
Feb.	.93	1508	3.62	1045
Mar.	.54	1525	1.00	1076
Apr.	.73	1547	3.24	1173
May	.81	1572	2.93	1264
June	.66	1592	3.00	1354
July	.72	1614	2.88	1443
Aug.	.73	1637	2.99	1536
1929				
Sept.	.66	1657	3.64	1645
Oct.	.73	1679	3.26	1746
Nov.	.83	1704	3.25	1844
Dec.	.73	1727	3.06	1938
1930				
Jan.	.83	1753	3.24	2039
Feb.	.72	1773	3.05	2134
Mar.	.78	1797	3.28	2236
Apr.	.84	1822	3.01	2326
May	.80	1847	3.27	2428
June	.68	1867	3.08	2520
July	.54	1884	3.24	2620
Aug.	.54	1901	2.89	2708
Sept.	.48	1915	2.76	2791
Oct.	.42	1928	2.51	2869
Nov.	.45	1942	2.81	2953
Dec.	.54	1959	3.43	3060
1931				
Jan.	.60	1977	3.32	3163
Feb.	.73	1998	3.20	3252
Mar.	.51	2013	2.94	3343
Apr.	.42	2026	2.59	3421
May	.39	2038	2.10	3486
June	.40	2050	1.70	3537
July	.33	2057	1.44	3582
Aug.	.26	2065	.92	3610
Sept.	.29	2074	.90	3637
Oct.	.28	2082	.84	3663
Nov.	.23	2089	.78	3687
Dec.	.22	2096	.75	3710
1932				
Jan.	.26	2104	1.29	3750
Feb.	.19	2110	.97	3778
Mar.	.22	2116	1.10	3812
Apr.	.24	2124	1.33	3852
May	.19	2130	1.10	3886
June	.17	2135	.95	3915
July	.18	2140	.89	3942
Aug.	.21	2147	.89	3969
Sept.	.19	2152	.93	3998
Oct.	.21	2159	.86	4024
Nov.	.21	2165	.90	4051
Dec.	.21	2172	.94	4081
1933				
Jan.	.20	2178	.89	4108
Feb.	.20	2184	.87	4133
Mar.	.22	2190	.84	4159
Apr.	.10	2193	.49	4173
May	.19	2200	.93	4202
June	.20	2206	.56	4219
July	.22	2213	.58	4237

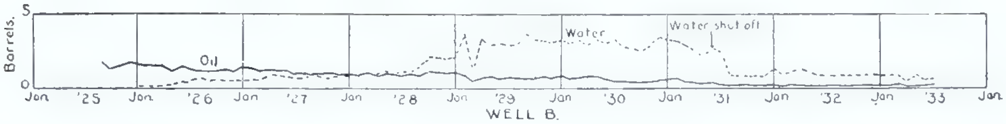

FIGURE 49. Curve showing average daily production of oil and water by months for well B in Flood No. 6.

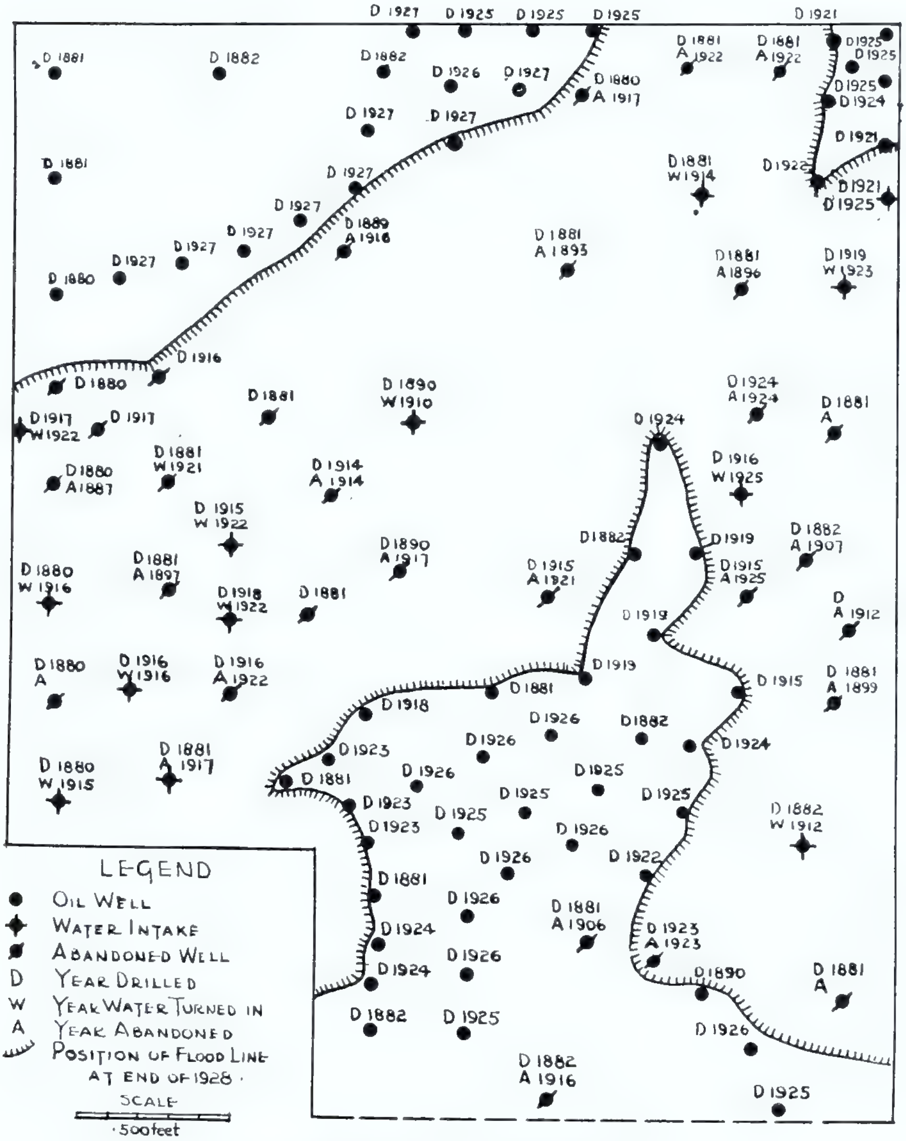

FIGURE 50. Map of Flood No. 7.

Flood No. 7

Flood No. 7 represents part of a large flood of the circle type in the southeastern lobe of the Bradford pool along the South Branch of Cole Creek. On the particular property shown in Figure 50, the effects of the flood first became noticeable in the production in 1913. During the succeeding 15 years, 135 acres were watered out. This flooded area yielded 408,700 barrels of oil, or 3,027 barrels per acre. The sand body on the tract, according to the drillers' records, averages 34 feet thick. Assuming that 70 percent is oil-bearing gives 24 feet of sandstone, which makes the yield 126 barrels per acre-foot. The average depth to the top of the sand in the intake wells is 1,604 feet, so that the maximum pressure possible by hydrostatic head was 700 pounds per

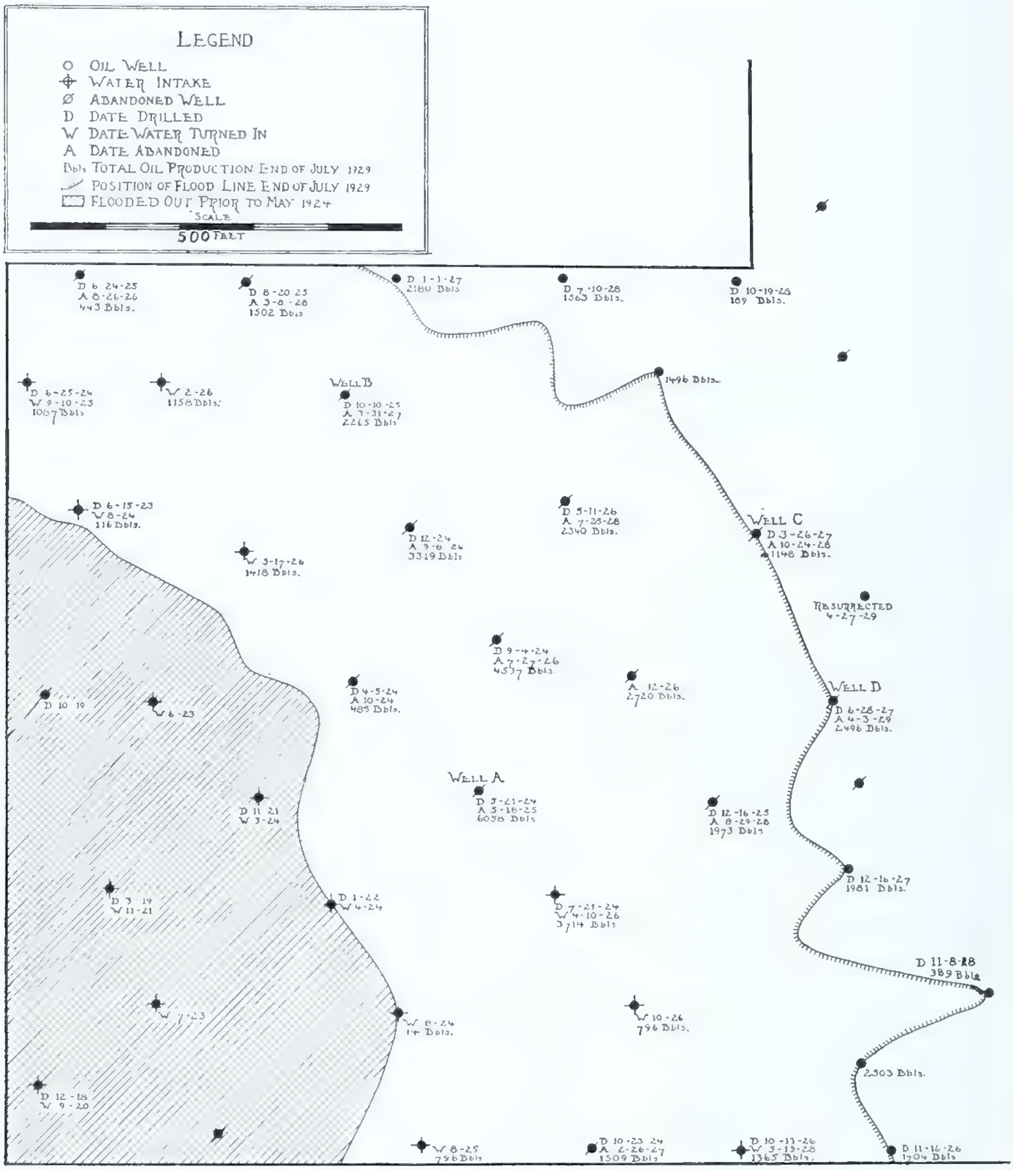
LEGEND
O OIL WELL
WATER INTAKE
Ø ABANDONED WELL
D DATE DRILLED
W DATE WATER TURNED IN
A DATE ABANDONED
Bbls TOTAL OIL PRODUCTION END OF JULY 1929
POSITION OF FLOOD LINE END OF JULY 1929
FLOODED OUT PRIOR TO MAY 1924
SCALE
500 FEET
D 6 24-25 A 8-26-26 443 Bbls.
D 8-20 25 A 3-8-28 1502 Bbls
D 1-1-27 2180 Bbls.
D 7-10-28 1563 Bbls.
D 10-19-28 189 Bbls.
D 6-25-24 W 9-10-25 1067 Bbls
W 2-26 1158 Bbls.
WELL B
D 10-10-25 A 7-31-27 2265 Bbls
1496 Bbls.
D 6-15-23 W 8-24 116 Bbls.
W 3-17-26 1418 Bbls.
D 12-24 A 9-6-26 3319 Bbls
D 5-11-26 A 7-25-28 2340 Bbls.
WELL C
D 3-26-27 A 10-24-28 1148 Bbls.
RESURRECTED 4-27-29
D 9-4-24 A 7-27-26 4537 Bbls.
D 10 19
W 6-23
D 4-5-24 A 10-24 485 Bbls.
A 12-26 2720 Bbls.
WELL D
D 6-28-27 A 4-3-29 2496 Bbls.
WELL A
D 5-21-24 A 5-18-25 6058 Bbls
D 11 21 W 3-24
D 12-16-25 A 8-29-28 1973 Bbls
D 12-16-27 1981 Bbls.
D 3 19 W 11-21
D 1-22 W 4-24
D 7-21-24 W 4-10-26 3714 Bbls
D 11-8-28 389 Bbls.
W 7-23
W 8-24 14 Bbls.
W 10-26 796 Bbls.
2503 Bbls.
D 12-18 W 9-20
W 8-25 796 Bbls
D 10-23 24 A 2-26-27 1509 Bbls
D 10-13-26 W 3-13-28 1365 Bbls.
D 11-16-26 1704 Bbls

FIGURE 51. Map of Flood No. 8.

square inch, inasmuch as only subsurface water was used. The sand under this tract is considerably more permeable than in the areas covered by the six floods thus far described.

Flood No. 8

Flood No. 8 is in the southeastern lobe of the Bradford pool west of Davis. A flood had come onto the property from the southwest and had already watered out a considerable area by May 1924 when the operation herein described started. This is shown in Figure 51. The sand on the property is quite permeable. During the 5¼ years following May 1924, the flood front advanced 600 feet or about 114 feet per year, as compared to 31 to 35 feet per year in Flood No. 1.

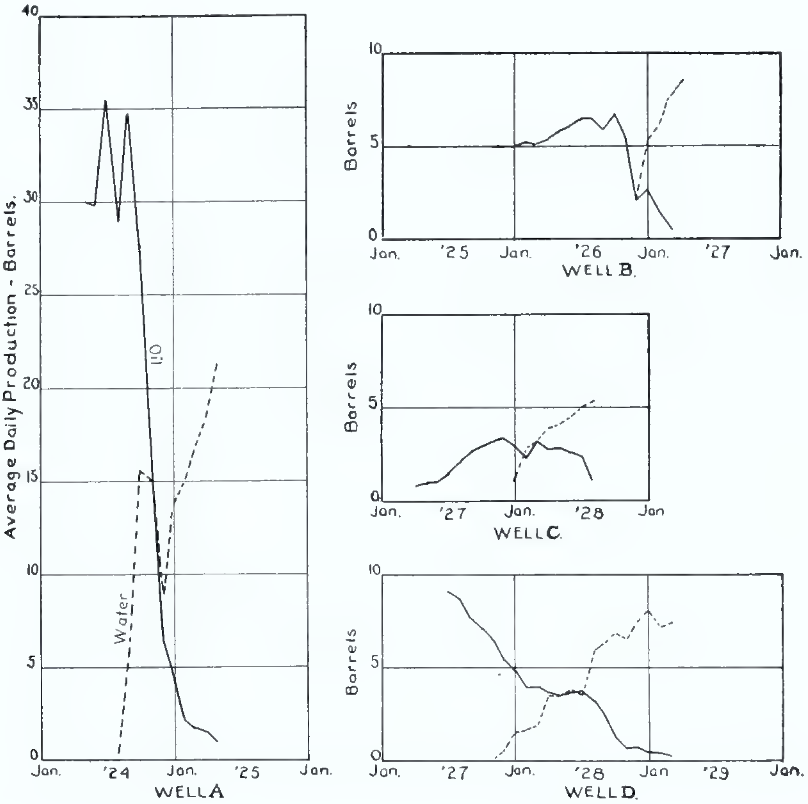

FIGURE 52. **Curves showing average daily production of oil and water by months for four wells in Flood No. 8.**

The 20.2 acres that were watered out in that period yielded 53,263 barrels of oil, or an average of 2,637 barrels per acre. The sand body, as shown by the drillers' records, averages 25 feet thick. Assuming that 80 percent of this is oil-bearing gives 20 feet of sandstone and makes the recovery 132 barrels per acre foot. The top of the sand occurs at an average depth of 2,020 feet, so that the maximum pressure possible by hydrostatic head was 875 pounds per square inch, inasmuch as only subsurface water entered the intake wells.

The average daily and cumulative oil and water production of four wells in Flood No. 8 by months are given in Table 77 and their average daily production is shown graphically in Figure 52. In this area of highly permeable sand, the behaviour of individual wells was very erratic. Owing to the rapid travel of the water through the sand, some wells were drilled too close to the advancing flood and their total yield, therefore, was small. Some of the wells had an unusually high daily production at their peak but declined rapidly. Once a well started to produce water, this increased so rapidly that the well was watered out within a comparatively short time. None of the wells were long-lived.

Table 77. Average daily and cumulative oil and water production of four wells in Flood No. 8 by months, in barrels

	Oil production		Water production	
Date	Daily	Cumulative	Daily	Cumulative
Well A				
1924				
May	30.00	30		
June	29.81	926		
July	35.45	2046		
Aug.	30.81	3001	.31	10
Sept.	34.77	4044	6.27	198
Oct.	27.74	4804	15.52	679
Nov.	16.62	5302	15.13	1133
Dec.	6.44	5502	8.72	1403
1925				
Jan.	4.31	5636	13.81	1831
Feb.	2.19	5697	15.00	2251
Mar.	1.72	5750	16.87	2774
Apr.	1.54	5797	18.36	3325
May	.92	5811	21.31	3666
Well B				
1925				
Nov.	5.00	80		
Dec.	5.00	235		
1926				
Jan.	5.00	390		
Feb.	5.25	537		
Mar.	5.10	695		
Apr.	5.32	855		
May	5.81	1035		
June	6.12	1219		
July	6.50	1355		
Aug.	6.50	1557		
Sept.	5.92	1734		
Oct.	6.73	1943		
Nov.	5.57	2110	2.32	70
Dec.	2.11	2175	5.36	236
1927				
Jan.	2.65	2257	6.08	424
Feb.	1.57	2301	7.73	638
Mar.	.66	2318	8.44	858
Well C				
1927				
Apr.	.87	12		
May	1.00	43		
June	1.00	73		
July	1.42	117		
Aug.	2.19	185		
Sept.	2.67	265		
Oct.	2.98	357		
Nov.	3.22	454		
Dec.	3.39	559		
1928				
Jan.	2.98	651	1.28	40
Feb.	2.34	719	2.82	122
Mar.	3.26	820	3.24	222
Apr.	2.80	904	3.92	340
May	2.82	992	4.11	467
June	2.64	1071	4.42	600
July	2.48	1048	4.96	754
Aug.	1.29	1188	6.24	947
Well D				
1927				
July	9.02	280		
Aug.	8.69	549		
Sept.	7.67	779		
Oct.	7.15	1000		
Nov.	6.63	1199	.06	2
Dec.	5.43	1368	.56	20
1928				
Jan.	4.91	1520	1.50	66
Feb.	4.00	1636	1.74	116
Mar.	4.00	1760	1.84	173
Apr.	3.70	1870	3.42	276
May	3.50	1978	3.47	383
June	3.67	2089	3.76	496
July	3.76	2205	3.42	603
Aug.	3.23	2305	5.89	785
Sept.	2.47	2380	6.22	972
Oct.	1.32	2420	6.81	1183
Nov.	.62	2439	6.57	1375
Dec.	.77	2463	7.52	1608
1929				
Jan.	.52	2479	8.06	1858
Feb.	.45	2492	7.25	2061
Mar.	.25	2500	7.43	2285

Flood No. 9

Flood No. 9 is in the southeastern lobe of the Bradford pool east of Big Shanty Station. Two tracts, as shown in Figure 53, are involved. The flood started originally from a single well in the western part of the eastern tract and affected the production of both tracts at about the same time.

On the western tract a line flood was started along the western boundary during 1924 in addition to the flood which was encroaching from the east. The production of this tract was first affected by flooding in 1921. During the next 14 years, 16.5 acres were watered out and yielded 62,760 barrels of oil, or an average of 3,804 barrels per acre. The sand body on this tract, according to the drillers' records, has an average thickness of 29 feet. Assuming that 64 percent is oil-bearing, gives 19 feet of sandstone and makes the yield 200 barrels per acre-foot. The top of the sand in the intake wells occurs at an average depth of 1,624 feet, so that the maximum pressure possible by hydrostatic head was 700 pounds per square inch, inasmuch as only subsurface water entered the intake wells.

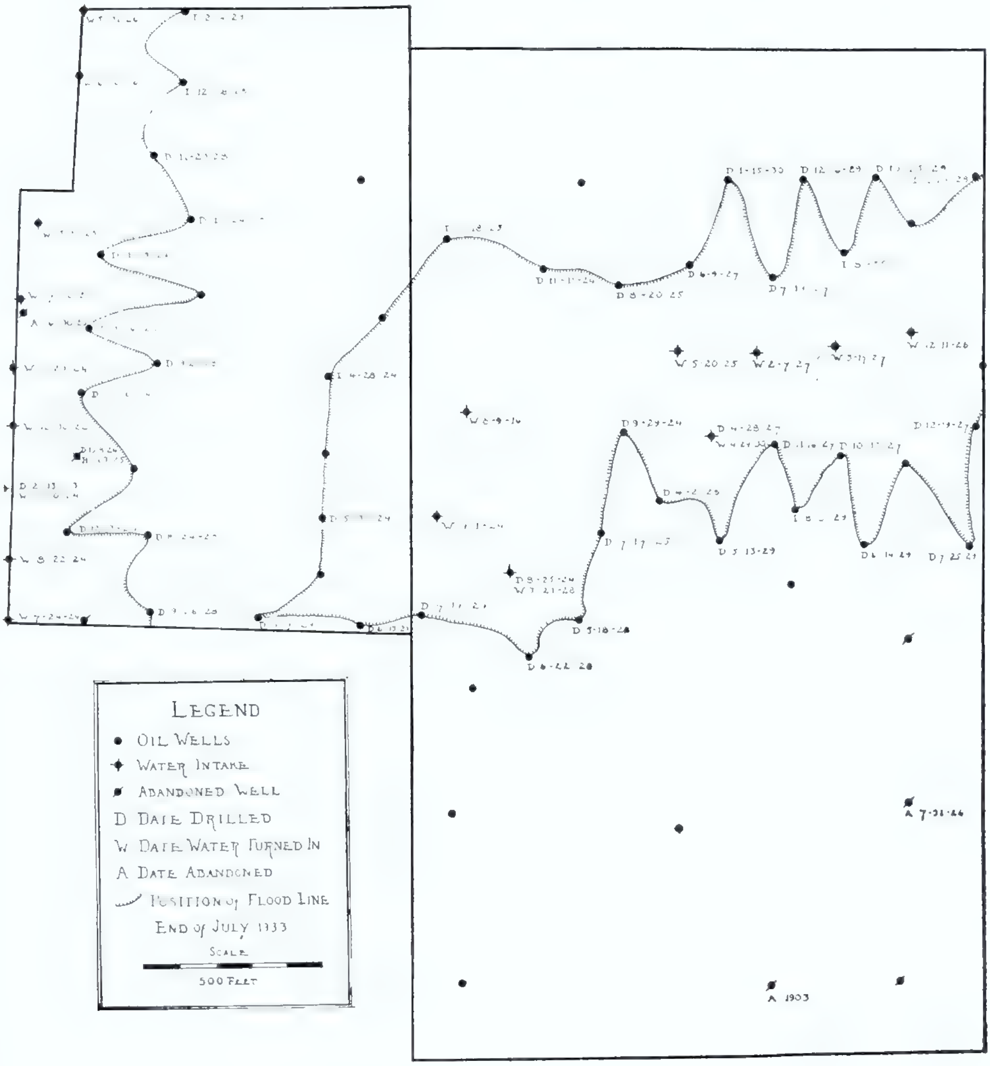

FIGURE 53. Map of Flood No. 9.

On the eastern tract effects of flooding on production first became noticeable in 1920. During the next 15 years, 30 acres were watered out and yielded 170,823 barrels of oil, or an average of 5,694 barrels per acre. The sand body on this tract, according to the drillers' records, has an average thickness of 30 feet. Assuming that 81 percent is oil-bearing sandstone gives 24 feet yielding 237 barrels per acre-foot. The top of the sand in the intake wells occurs at an average depth of 1,958 feet, so that the maximum pressure possible by hydrostatic head was 850 pounds per square inch inasmuch as only subsurface water entered the intake wells.

The average daily oil production per well by years for both the western and the eastern tracts of Flood No. 9 are given in Table 78.

Table 78. Average daily oil production per well for Flood No. 9 by years

Western Tract						**Eastern Tract**					
Before water-flooding started			After water-flooding started			Before water-flooding started			After water-flooding started		
Year	No. of wells producing	Oil per well bbls.	Year	No. of wells producing	Oil per well bbls.	Year	No. of wells producing	Oil per well bbls.	Year	No. of wells producing	Oil per well bbls.
1893	7	.54	1921	7	.30	1893	15	.64	1920	12	.38
1894	7	.52	1922	7	.51	1894	15	.55	1921	12	.54
1895	7	.45	1923	7.9	.41	1895	15	.52	1922	12	.66
1896	7	.59	1924	9.3	1.70	1896	15	.51	1923	12	.36
1897	7	.52	1925	11.7	2.47	1897	15	.43	1924	12.5	.99
1898	7	.43	1926	11.3	1.82	1898	15	.40	1925	15.8	2.19
1899	7	.42	1927	13.0	1.23	1899	15	.40	1926	16.4	2.21
1900	7	.41	1928	14.1	1.17	1900	15	.37	1927	17.5	3.72
1901	7	.35	1929	20.8	.94	1901	15	.32	1928	23.9	4.25
1902	7	.37	1930	21.0	.59	1902	15	.33	1929	27.3	2.41
1903	7	.41	1931	21.0	.54	1903	14	.38	1930	31.3	1.36
1904	7	.33	1932	21.0	.49	1904	14	.37	1931	31.0	.93
1905	7	.28	1933	21.0	.38	1905	14	.36	1932	31.0	.62
1906	7	.27	1934	21.0	.35	1906	14	.31	1933	31.0	.82
1907	7	.24				1907	14	.30	1934	31.0	.76
1908	7	.21	Water intake wells shut off permanently during curtailment period of 1930-'32			1908	14	.28			
1909	7	.24				1909	14	.29	Water intake wells shut off permanently during curtailment period of 1930-'32		
1910	7	.32				1910	14	.29			
1911	7	.28				1911	14	.28			
1912	7	.27				1912	14	.26			
1913	7	.26				1913	13	.29			
1914	7	.32				1914	13	.33			
1915	7	.28				1915	13	29			
1916	7	.25				1916	12.6	.26			
1917	7	.26				1917	12	.29			
1918	7	.24				1918	12	.26			
1919	7	.21				1919	12	.26			
1920	7	.20									

LINE FLOODS

Flood No. 10

Flood No. 10, shown in Figure 54, is a line flood in the northwestern lobe of the Bradford pool east of South Bradford. The distance between the rows of wells is 110 feet and the wells are 210 feet apart in the rows, making the distance from water intake to oil well approximately 152 feet. These distances were varied slightly to adjust the line to the width of the property and to include three old wells which were made part of the pattern. The intake wells were completed and subsurface water let in between March and August, 1925. The first rows of oil wells on each side of the intake wells were completed between September 1925, and May 1926. The peak of production for the group as a whole came in May 1926. Normally, these wells would have been converted into intake wells at about the end of 1928. Inasmuch, however, as it was foreseen at that time that this method of operating would be abandoned shortly, pumping was continued for nearly a year and a half longer. The second rows of oil wells on each side of the intake row were completed between September 1926, and May 1927. Their peak of production came in March 1929.

A total of 70,965 barrels of oil was recovered from the 16.6 acres watered out in this operation, or an average of 4,275 barrels per acre. The sand body has an average thickness of 37 feet, according to the drillers' records. Assuming that 65 percent is oil-bearing sandstone gives 24 feet yielding 178 barrels per acre-foot.

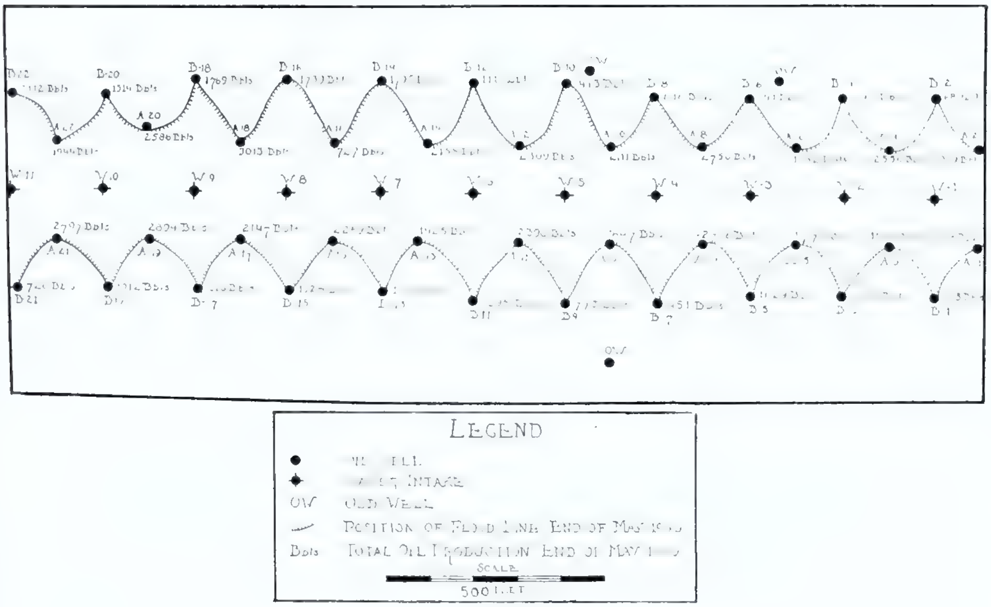

FIGURE 54. Map of Flood No. 10.

Only subsurface water entered the intake wells at the start. The average depth to the top of the sand is 1,630 feet so that the maximum average pressure possible by hydrostatic head was 700 pounds per square inch. In November, 1928, water was first admitted at the top of the wells. This was obtained from a small stream nearby. It was under just sufficient head to reach the top of the highest well in which the sand occurs at a depth of 1,812 feet, making the pressure at the face of the sand 785 pounds per square inch. This had almost no effect on the total oil production of the first group of oil wells, but it did increase that of the second group from 545 barrels per month in October, 1928, to 715 barrels in March, 1929. The water output of the first group of wells was noticeably increased. The quantity of water which entered each intake well from November, 1928, to the end of May, 1930, when the operation was discontinued, is given in Table 79.

Table 79. Water input from November 8, 1928, to the end of May, 1930, for Flood No. 10.

Well No.	Barrels	Well No.	Barrels
W-1	9,420	W-6	8,855
W-2	5,875	W-7	11,390
W-3	13,329	W-8	5,460
W-4	3,812	W-9	19,749
W-5	10,100	W-10	14,201

The average daily oil production per well and the cumulative production of the two groups of wells in Flood No. 10 by months are given in Table 80. The former are shown graphically in Figure 55. The average daily and cumulative oil and water production of four of these wells are given in Tables 81 and 82 and are also shown graphically in Figure 55. The water output to oil ratios for the individual wells in the two groups, in so far as they were available, are given in Table 83. The average total oil recovery per well for the A-group was 2,092 barrels and for the B-group, 1,133 barrels.

One old well, W-1, was converted into a water intake. As shown in Table 79, it proved to be about as efficient as the average of the group. Two old wells, A-13 and A-20, were incorporated in the line flood as oil wells. A-13 produced only 1,425 barrels of oil, which was considerably below the average for the group, but A-20 produced 2,586 barrels, which was appreciably above the average. Well A-13 by-passed water in large quantity, having had the highest water output to oil ratio for the entire group. However, a new well, B-13, also had a high ratio for its group, so that this behaviour was probably due to a local sand condition rather than the fact that A-13 was an old well.

Table 80. Average daily oil production per well and cumulative production of A and B groups in Flood No. 10 by months, in barrels.

Group A

Date	No. wells	Daily	Cumulative
1925			
Sept.	1	.95	28
Oct.	3	1.73	190
Nov.	5	1.56	424
Dec	8	1.14	708
1926			
Jan.	10	1.81	1,268
Feb.	9	3.52	2,155
Mar.	16	3.19	3,737
April	19	3.48	5,722
May	21	3.06	7,714
June	22	2.99	9,685
July	22	2.91	11,669
Aug.	22	2.83	13,602
Sept.	22	2.86	15,490
Oct.	22	2.62	17,275
Nov.	22	2.70	18,959
Dec.	22	2.47	20,646
1927			
Jan.	22	2.49	22,342
Feb.	22	2.22	23,710
March	22	2.12	25,154
April	22	1.99	26,471
May	22	1.90	27,768
June	22	1.78	28,946
July	22	1.80	30,129
Aug.	22	1.51	31,160
Sept.	22	1.34	32,041
Oct.	22	1.25	32,891
Nov.	22	1.11	33,621
Dec.	21	1.09	34,335
1928			
Jan.	21	1.13	35,070
Feb.	21	1.19	35,771
March	21	1.07	36,468
April	21	.99	37,082
May	21	.84	37,630
June	21	.78	38,123
July	20	.69	38,552
Aug.	21	.67	38,990
Sept.	21	.67	39,415
Oct.	20	.54	39,747
Nov.	21	.54	40,085
Dec.	21	.64	40,504
1929			
Jan.	20	.64	40,899
Feb.	21	.62	41,264
March	21	.65	41,690
April	21	.62	42,081
May	21	.62	42,483
June	21	.60	42,863
July	21	.61	43,262
Aug.	20	.59	43,625
Sept.	20	.57	43,970
Oct.	20	.53	44,307
Nov.	20	.54	44,631
Dec.	20	.53	44,958
1930			
Jan.	20	.38	45,191
Feb.	20	.33	45,376
March	20	.36	45,597
April	20	.36	45,813
May	20	.33	46,019
June	20		

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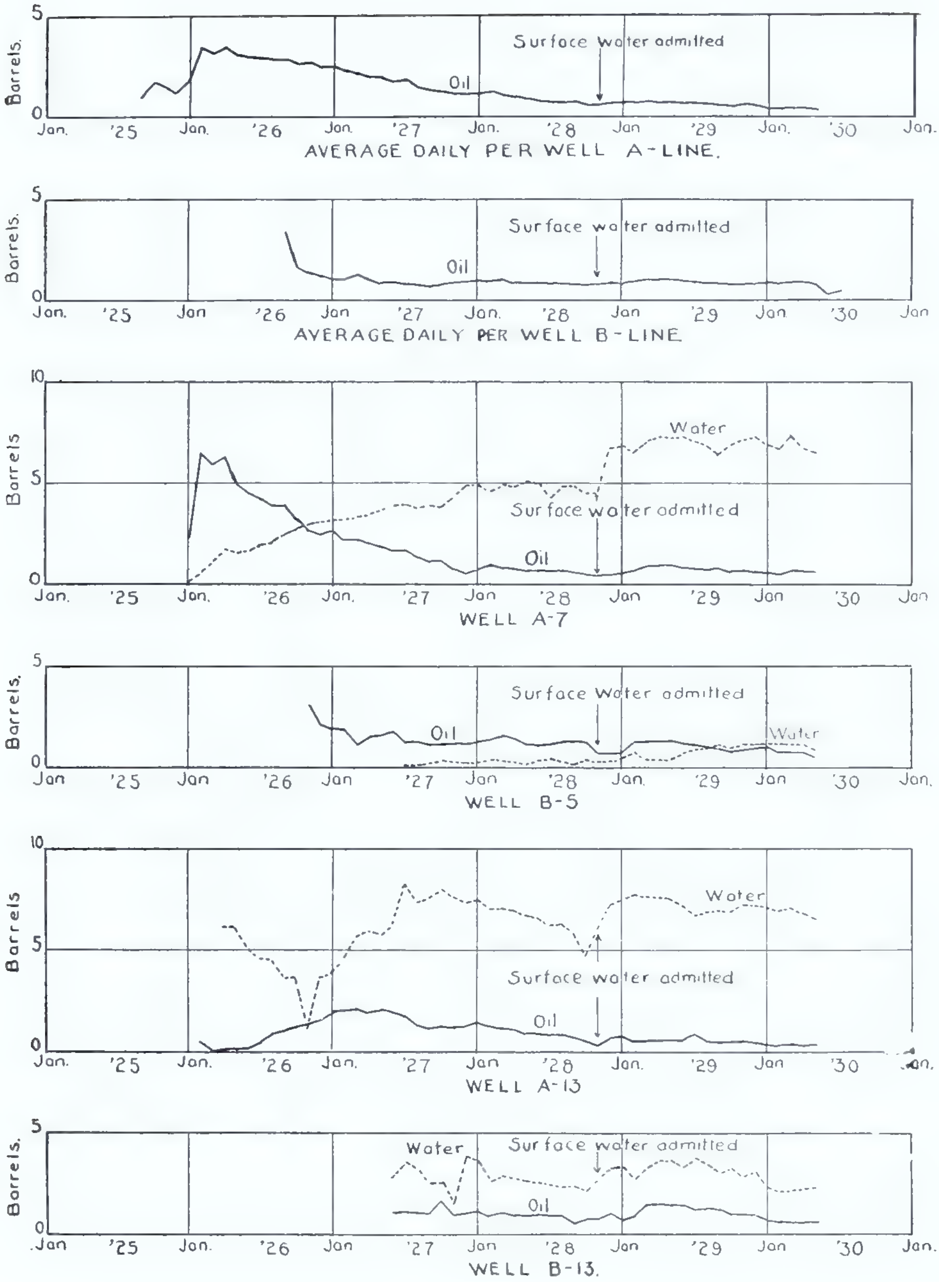


Figure 55. Curves showing average daily oil production per well of A and B group wells and average daily oil and water production of four wells by months in Flood No. 10

Table 80 (Continued)

Group B

Date	No. wells	Daily	Cumulative
1926			
Sept.	2	3.29	198
Oct.	4	1.71	409
Nov.	6	1.45	671
Dec.	7	1.26	944
1927			
Jan.	9	1.08	1,244
Feb.	12	1.07	1,603
March	16	1.31	2,253
April	17	1.07	2,801
May	17	.92	3,286
June	21	.92	3,864
July	22	.83	4,433
Aug.	22	.80	4,976
Sept.	21	.75	5,449
Oct.	21	.77	5,953
Nov.	22	.82	6,493
Dec.	22	.91	7,104
1928			
Jan.	22	.99	7,778
Feb.	22	.99	8,391
March.	22	1.02	9,088
April	22	.97	9,729
May	22	.92	10,357
June	22	.89	10,942
July	22	.87	11,537
Aug.	22	.86	12,126
Sept.	22	.83	12,674
Oct.	22	.80	13,217
Nov.	22	.83	13,763
Dec.	22	.87	14,354
1929			
Jan.	22	.86	14,944
Feb.	22	.96	15,535
March	22	1.05	16,249
April	22	1.04	16,933
May	22	1.04	17,643
June	22	1.01	18,312
July	22	.99	18,986
Aug.	22	.88	19,588
Sept.	22	.86	20,152
Oct.	22	.83	20,719
Nov.	22	.83	21,268
Dec.	22	.85	21,844
1930			
Jan.	22	.91	22,462
Feb.	22	.84	22,980
March	22	.90	23,596
April	22	.94	24,216
May	22	.89	24,805
June	8	.36	24,893
July	4	.43	24,946

Table 81. Average daily and cumulative oil and water production of wells A-7 and B-5 in Flood No. 10 by months, in barrels.

Group A-7

	Oil production		Water production	
Date	Daily	Cumulative	Daily	Cumulative
1926				
Jan.	2.37	73	.08	2
Feb.	6.47	254	.61	19
March	5.82	435	1.17	56
April	6.27	623	1.74	108
May	4.94	776	1.61	158
June	4.59	914	1.71	209
July	4.22	1,044	1.96	270
Aug.	3.91	1,166	2.06	334
Sept.	3.87	1,282	2.47	408
Oct.	3.27	1,383	2.78	494
Nov.	2.62	1,461	2.86	580
Dec.	2.46	1,538	3.02	673
1927				
Jan.	2.70	1,622	3.19	772
Feb.	2.19	1,683	3.22	862
March	2.21	1,752	3.37	967
Apri	2.09	1,814	3.42	1,070
May	1.90	1,873	3.62	1,182
June	1.70	1,924	3.87	1,298
July	1.67	1,976	3.93	1,419
Aug.	1.40	2,019	3.80	1,537
Sept.	1.14	2,054	3.86	1,653
Oct.	1.14	2,089	3.80	1,771
Nov.	.76	2,112	4.32	1,901
Dec.	.57	2,129	4.88	2,052
1928				
Jan.	.72	2,152	4.98	2,206
Feb.	.95	2,179	4.60	2,340
March	.84	2,205	4.89	2,391
April	.76	2,228	4.85	2,637
May	.72	2,250	5.13	2,796
June	.72	2,272	5.04	2,947
July	.69	2,293	4.30	3,080
Aug.	.62	2,313	4.85	3,231
Sept.	.57	2,330	4.90	3,378
Oct.	.52	2,346	4.52	3,518
Nov.	.43	2,359	4.56	3,655
Dec.	.53	2,375	6.75	3,864
1929				
Jan.	.57	2,393	6.84	4,076
Feb.	.67	2,412	6.56	4,260
March.	.95	2,441	7.09	4,479
April	.95	2,470	7.22	4,696
May	.95	2,499	7.22	4,920
June	.83	2,524	7.27	5,138
July	.80	2,548	7.11	5,358
Aug.	.76	2,572	6.94	5,574
Sept.	.78	2,595	6.46	5,767
Oct.	.70	2,617	6.84	5,979
Nov.	.72	2,639	7.12	6,193
Dec.	.69	2,660	7.26	6,418
1930				
Jan.	.60	2,679	6.91	6,632
Feb.	.49	2,693	6.66	6,819
March	.73	2,716	7.35	7,047
April	.69	2,737	6.74	7,249
May	.62	2,756	6.53	7,451

Table 81. (Continued)

Group B-5

Date	Oil production		Water production	
	Daily	Cumulative	Daily	Cumulative
1926				
Nov.	3.13	94		
Dec.	2.09	159		
1927				
Jan.	1.90	2.17		
Feb.	1.83	269		
March	1.17	322		
April	1.52	367		
May	1.59	417		
June	1.76	469		
July	1.29	509	.10	3
Aug.	1.23	548	.11	6
Sept.	1.15	582	.20	12
Oct.	1.14	617	.38	24
Nov.	1.14	652	.30	33
Dec.	1.17	688	.23	40
1928				
Jan.	1.23	726	.29	49
Feb.	1.33	765	.38	60
March	1.56	813	.36	71
April	1.48	857	.34	82
May	1.14	892	.19	88
June	1.12	926	.34	98
July	1.14	962	.38	110
Aug.	1.26	1,001	.27	118
Sept.	1.31	1,040	.19	124
Oct.	1.29	1,080	.34	134
Nov.	.76	1,103	.29	143
Dec.	.76	1,126	.34	153
1929				
Jan.	.76	1,149	.38	165
Feb.	1.24	1,184	.76	186
March	1.33	1,225	.38	198
Apri	1.33	1,265	.38	210
May	1.33	1,306	.38	221
June	1.24	1,343	.76	244
July	1.14	1,379	.91	272
Aug.	1.04	1,411	.97	303
Sept.	.95	1,439	1.05	334
Oct.	.81	1,464	.95	363
Nov.	.91	1,492	1.14	398
Dec.	.95	1,521	1.14	433
1930				
Jan.	.80	1,546	1.21	471
Feb.	.77	1,567	1.21	504
March	.76	1,591	1.16	540
April	.76	1,614	1.14	575
May	.49	1,629	.83	600

Table 82. Average daily and cumulative oil and water production of wells A-13 and B-13 in Flood No. 10 by months, in barrels.

Group A-13

Date	Oil production		Water production	
	Daily	Cumulative	Daily	Cumulative
1926				
Feb.	.42	12	3.48	97
March		12		97
April	.09	14	6.08	280
May	.17	20	6.08	468
June	.19	25	5.00	618
July	.44	39	4.56	760
August	.84	65	4.40	896
Sept.	1.02	96	3.58	1,003
Oct.	1.30	136	3.68	1,117
Nov.	1.40	178	1.09	1,150
Dec.	1.55	226	3.70	1,265
1927				
Jan.	1.97	287	3.90	1,386
Feb.	2.05	344	4.60	1,515
March	2.08	409	5.64	1,689
April	1.96	468	5.89	1,866
May	2.02	530	5.76	2,045
June	1.96	589	6.21	2,231
July	1.83	646	8.26	2,487
August	1.30	686	7.34	2,714
Sept.	1.19	722	7.60	2,915
Oct.	1.33	763	7.98	3,190
Nov.	1.20	799	7.72	3,422
Dec.	1.23	837	7.37	3,650
1928				
Jan.	1.40	881	7.45	3,881
Feb.	1.23	916	7.03	4,085
March	1.18	953	7.07	4,304
April	1.10	986	6.94	4,512
May	.88	1,013	6.71	4,720
June	.93	1,041	6.61	4,918
July	.82	1,066	6.21	5,111
Aug.	.86	1,093	6.27	5,305
Sept.	.69	1,114	5.85	5,481
Oct.	.57	1,132	4.66	5,625
Nov.	.30	1,140	5.82	5,800
Dec.	.67	1,161	7.29	6,026
1929				
Jan.	.76	1,185	7.47	6,258
Feb.	.54	1,200	7.73	6,474
March	.57	1,218	7.68	6,712
April	.57	1,235	7.60	6,940
May	.57	1,253	7.60	7,176
June	.55	1,269	7.22	7,392
July	.82	1,295	6.77	7,602
Aug.	.53	1,311	6.95	7,818
Sept.	.48	1,326	6.97	8,027
Oct.	.48	1,341	6.90	8,241
Nov.	.50	1,356	7.26	8,458
Dec.	.46	1,370	7.22	8,682
1930				
Jan.	.38	1,381	7.15	8,904
Feb.	.32	1,394	6.97	9,099
March	.35	1,404	7.07	9,318
April	.33	1,414	6.83	9,523
May	.32	1,424	6.52	9,725

Table 82. (Continued)

Group B-13

Date	Oil production Daily	Oil production Cumulative	Water production Daily	Water production Cumulative
1927				
June	1.13	34	2.88	86
July	1.14	69	3.60	198
Aug.	1.13	104	3.24	298
Sept.	1.10	137	2.46	372
Oct.	1.69	190	2.57	452
Nov.	.97	219	1.55	498
Dec.	1.02	250	3.91	620
1928				
Jan.	1.18	287	3.66	733
Feb.	.95	314	2.66	810
March	1.09	348	2.85	898
April	.95	377	2.76	1,062
May	95	406	2.62	981
June	.98	436	2.60	1,140
July	.95	465	2.47	1,217
Aug.	.95	494	2.36	1,290
Sept.	.59	512	2.38	1,361
Oct.	.72	534	2.16	1,428
Nov.	.78	558	2.71	1,510
Dec.	1.07	591	3.29	1,612
1929				
Jan.	.78	615	3.33	1,715
Feb.	1.00	643	2.62	1,788
March	1.52	690	3.32	1,891
April	1.52	736	3.66	2,001
May	1.48	782	3.71	2,116
June	1.50	827	3.38	2,217
July	1.24	865	3.80	2,335
Aug.	1.31	906	3.57	2,446
Sept.	1.26	944	3.04	2,537
Oct.	1.07	977	3.28	2,639
Nov.	1.02	1,007	2.94	2,727
Dec.	.98	1,038	3.17	2,825
1930				
Jan.	.76	1,061	2.29	2,896
Feb.	.70	1,081	2.08	2,954
March	.67	1,102	2.19	3,022
April	.67	1,122	2.25	3,090
May	.62	1,141	2.25	3,159

Table 83. Water output to oil ratios for A and B-group wells of Flood No. 10.

Group A

Well No.	Water output Bbls	Oil production Bbls.	Water output to oil ratio
A-3	5,747	1,807	3.18
A-4	4,380	2,550	1.72
A-5	9,039	1,775	5.09
A-6	5,814	1,951	2.98
A-7	7,451	2,756	2.70
A-8	7,618	2,750	2.77
A-9	6,666	1,647	4.05
A-10	5,625	2,111	2.66
A-11	8,573	2,398	3.58
A-12	7,755	2,309	3.36
A-13	9,725	1,425	6.83
A-17	6,188	2,147	2.88
A-21	6,518	2,797	2.33
Total	91,097	28,422	3.21

Group B

Well No.	Water output Bbls	Oil production Bbls.	Water output to oil ratio
B-1	66	735	.09
B-2	21	689	.03
B-3	239	1,154	.21
B-4	49	1,362	.04
B-5	600	1,629	.37
B-6	349	941	.37
B-9	130	775	.17
B-10	820	413	1.99
B-11	102	1,395	.07
B-12	557	1,119	.50
B-13	3,160	1,141	2.77
B-15	363	1,027	.35
B-16	6,444	1,739	3.71
B-17	328	616	.53
B-18	624	1,769	.35
B-19	273	1,012	.27
B-20	700	1,514	.46
B-21	283	726	.39
B-22	1,989	2,112	.94
Total	17,296	21,866	.79

Flood No. 11

Flood No. 11, shown in Figure 56, is a small line flood in the northwestern lobe of the Bradford pool along Sheppard Run west of Custer City. The rows of wells are 120 feet apart and the distance between wells is 242 feet, making the distance between water intake and oil wells 170 feet. Two old wells were included in the pattern. The intake wells were completed and subsurface water let in between July and October, 1934. The first row of oil wells was completed during October and November, 1924. Two of these wells were watered out and converted into intake wells by the end of March 1929.

A total of 14,980 barrels of oil was recovered from the 3.5 acres watered out in five years, or an average of 4,280 barrels per acre. Only one-half of the production of well C is included in this total. According to the drillers'

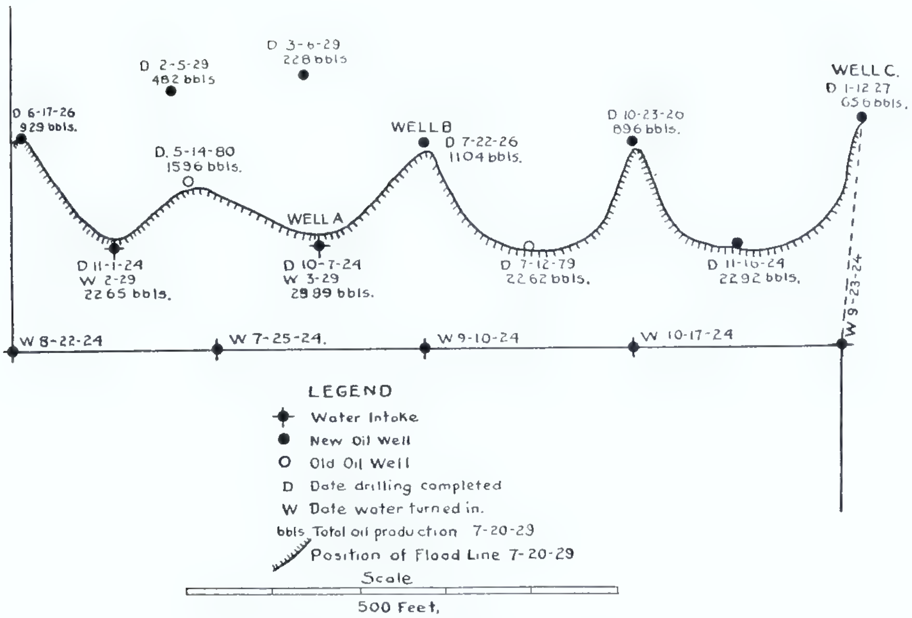


FIGURE 56. Map of Flood No. 11.

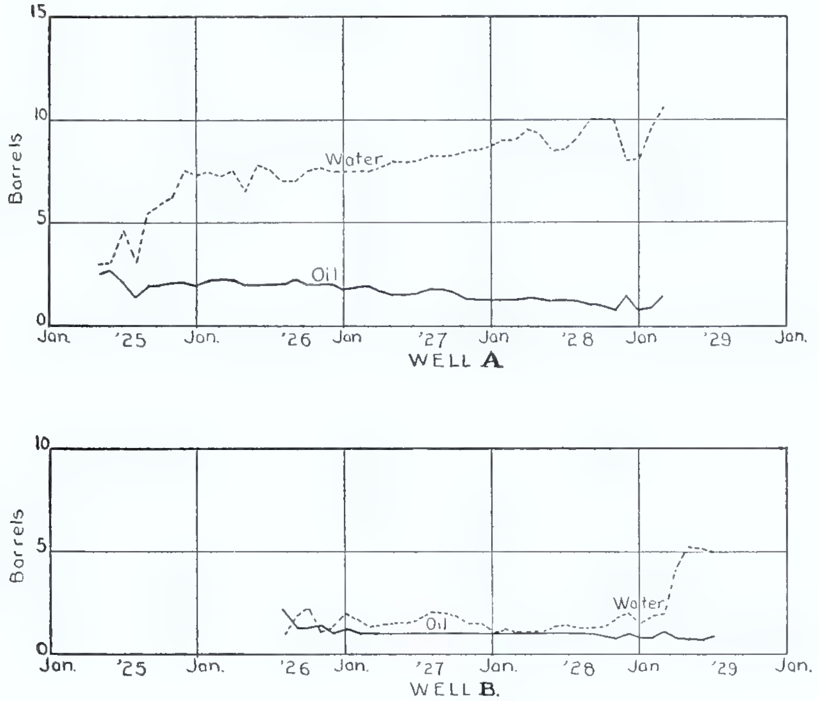


FIGURE 57. Curves showing average daily oil and water production by months of two wells in Flood No. 11.

records, the sand body on this tract has an average thickness of 38 feet. Assuming that 74 percent is oil-bearing sandstone gives 28 feet, from which the recovery was 153 barrels per acre-foot. The top of the sand in the intake wells occurs at an average depth of 1,557 feet. The average pressure possible by hydrostatic head, therefore, was 675 pounds.

The average daily and cumulative oil and water production by months of two wells in Flood No. 11 are given in Table 84 and their average daily yields by months are shown graphically in Figure 57. As shown in Figure 56, the two old wells in this flood compared favorably in yield with the new wells.

Table 84. Average daily and cumulative oil and water production of two wells in Flood No. 11 by months, in barrels.

Well A

Date	Oil production		Water production	
	Daily	Cumulative	Daily	Cumulative
1925				
May	2.50	77	3.00	93
June	2.68	158	3.11	186
July	2.12	223	4.68	331
Aug.	1.35	265	3.19	430
Sept.	1.89	322	5.48	595
Oct.	1.97	383	5.87	777
Nov.	2.06	445	6.22	963
Dec.	2.15	511	7.49	1,195
1926				
Jan.	2.01	574	7.31	1,422
Feb.	2.20	635	7.47	1,631
March	2.31	707	7.27	1,856
April	2.25	774	7.55	2,083
May	2.01	836	6.74	2,292
June	2.00	896	7.81	2,526
July	2.00	958	7.64	2,763
Aug.	2.00	1,020	7.02	2,981
Sept.	2.22	1,087	7.03	3,192
Oct.	2.07	1,151	7.47	3,423
Nov.	2.00	1,211	7.73	3,655
Dec.	2.00	1,273	7.50	3,888
1927				
Jan.	1.81	1,329	7.50	4,120
Feb.	1.83	1,381	7.50	4,330
March	1.96	1,441	7.50	4,563
April	1.63	1,490	7.79	4,796
May	1.50	1,537	8.00	5,044
June	1.50	1,582	8.00	5,284
July	1.56	1,630	8.06	5,534
Aug.	1.75	1,685	8.25	5,790
Sept.	1.75	1,737	8.25	6,038
Oct.	1.60	1,787	8.27	6,294
Nov.	1.32	1,826	8.50	6,549
Dec.	1.24	1,865	8.56	6,814
1928				
Jan.	1.25	1,904	8.77	7,086
Feb.	1.25	1,940	9.00	7,347
March	1.25	1.979	9.00	7,626
April	1.33	2,018	9.50	7,911
May	1.29	2,058	9.34	8,201
June	1.25	2,096	8.50	8,456
July	1.25	2,135	8.61	8,723
Aug.	1.20	2,172	9.13	9,006
Sept.	1.00	2,202	10.00	9,306
Oct.	.97	2,232	10.00	9,616
Nov.	.75	2,254	10.00	9,916
Dec.	1.44	2,299	8.06	10,166
1929				
Jan.	.79	2,324	8.11	10,417
Feb.	.86	2,348	9.62	10,686
March.	1.40	2,360	10.56	10,781

Well B

Date	Oil production		Water production	
	Daily	Cumulative	Daily	Cumulative
1926				
Aug.	2.23	53	1.00	24
Sept.	1.28	92	1.87	80
Oct.	1.25	131	2.23	149
Nov.	1.40	173	1.12	182
Dec.	1.00	204	1.33	224
1927				
Jan.	1.22	242	1.94	284
Feb.	1.00	270	1.62	329
March	1.00	301	1.33	370
April	1.00	331	1.41	412
May	1.00	362	1.50	459
June	1.00	392	1.50	504
July	1.00	423	1.63	554
Aug.	1.00	453	2.00	616
Sept.	1.00	484	2.00	676
Oct.	1.00	515	1.85	734
Nov.	1.00	545	1.50	779
Dec.	1.00	576	1.50	825
1928				
Jan.	1.00	607	1.02	857
Feb.	1.00	636	1.18	891
March	1.00	667	1.05	924
April	1.00	697	1.00	954
May	1.00	728	1.05	986
June	1.00	758	1.33	1,026
July	1.00	789	1.41	1,070
Aug.	1.00	820	1.33	1,111
Sept.	1.00	850	1.33	1,151
Oct.	.97	880	1.33	1,192
Nov.	.80	904	1.68	1,243
Dec.	1.00	935	2.00	1,305
1929				
Jan.	.82	960	1.51	1,352
Feb.	.81	983	1.83	1,403
March	1.08	1,016	1.94	1,463
April	.81	1,040	4.20	1,589
May	.79	1,065	5.27	1,752
June	.74	1,087	5.19	1,908
July	.84	1,103	5.00	2,008

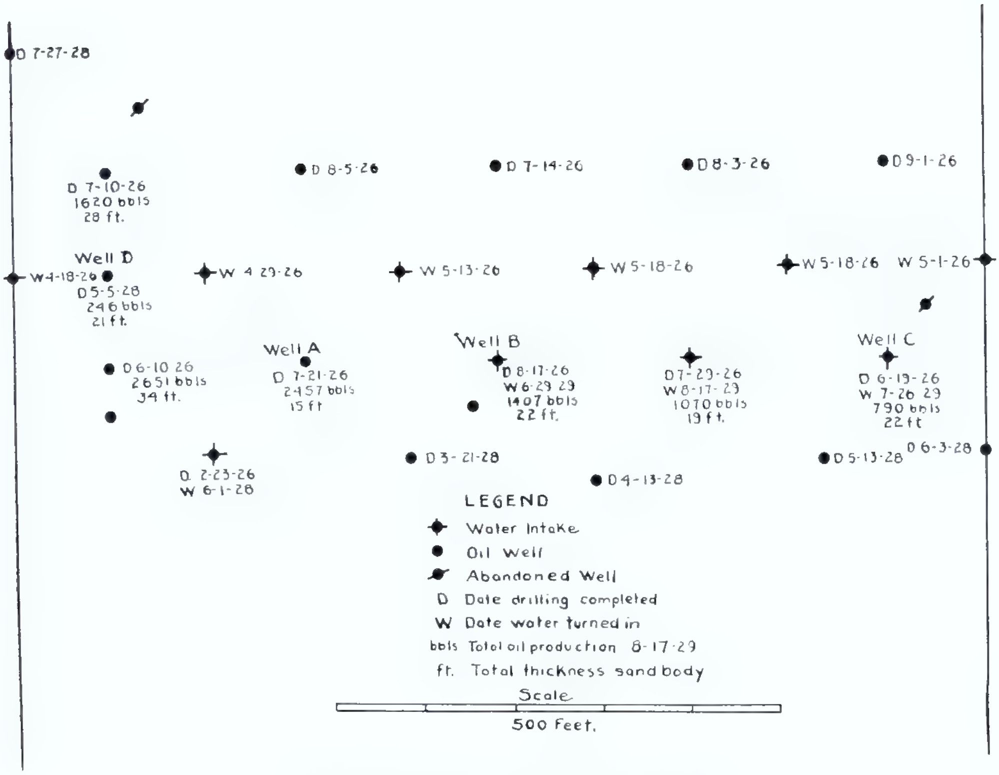


FIGURE 58. Map of Flood No. 12.

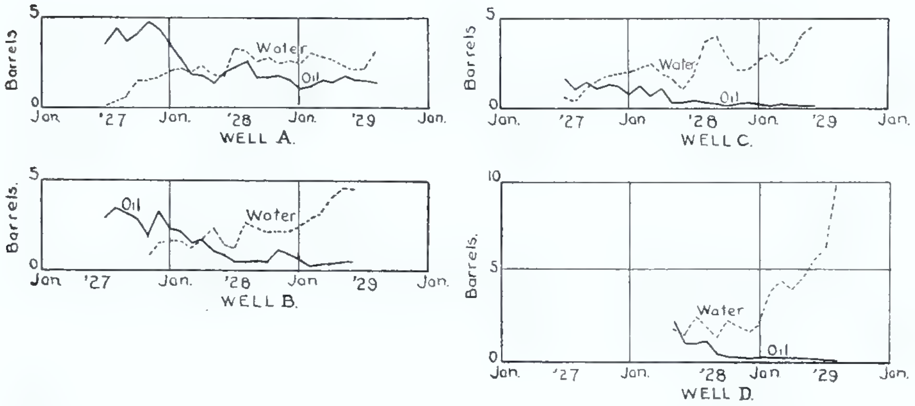


FIGURE 59. Curves showing average daily oil and water production by months of four wells in Flood No. 12.

Flood No. 12

Flood No. 12 is a line flood in the northeastern portion of the Bradford pool near Duke Center. The rows of wells are 110 feet apart and wells in the rows 220 feet, making the distance from water intake to oil well 156 feet. This was one of the first properties in the Bradford district on which water under pressure was introduced into the intake wells. A pressure plant operating at 300 pounds per square inch was started in April 1927. This gave a pressure of 800 pounds per square inch at the face of the sand.

The sand on the tract is comparatively thin and is probably interbedded with considerable shale. The average thickness of the sand body, according to drillers' records, is 24 feet. In this vicinity probably only 55 percent or 13 feet is oil-bearing sandstone. A little over three years was required to water-out the first row of oil wells. The yield per well, as shown in Figure 58, was comparatively small. The wells at the left had a large production because a water-drive was also moving in their direction from the lower side at the left end of the line.

The average daily and the cumulative oil and water production of four of the wells in Flood No. 12 is given in Tables 85 and 86. The former is shown graphically in Figure 59.

Well D was drilled midway between two intake wells two years after the water had been turned into the latter. The production record of this well shows that the flood front had practically reached this point when the well was drilled. The amount of oil recovered from it was almost negligible.

Table 85. Average daily and cumulative oil and water production of wells A and B in Flood No. 12 by months, in barrels.

Well A

	Oil production		Water production	
Date	Daily	Cumulative	Daily	Cumulative
*Prior		638		
1927				
July	3.52	747	.03	1
Aug.	4.34	882	.35	12
Sept.	3.67	992	.65	31
Oct.	4.03	1,117	1.53	79
Nov.	4.70	1,258	1.57	126
Dec.	4.45	1,396	1.73	179
1928				
Jan.	3.56	1,506	2.00	241
Feb.	2.74	1,585	2.15	304
March	1.85	1,643	1.98	365
April	1.80	1,697	2.35	436
May	1.35	1,739	1.87	494
June	1.99	1,799	1.76	546
July	2.24	1,868	3.26	648
Aug.	2.52	1,946	3.13	745
Sept.	1.64	1,995	2.50	820
Oct.	1.64	2,046	2.74	904
Nov.	1.75	2,099	2.50	979
Dec.	1.53	2,146	2.53	1,058
1929				
Jan.	1.03	2,178	2.43	1,133
Feb.	1.18	2,211	3.00	1,217
March	1.46	2,256	2.85	1,306
April	1.38	2,298	2.66	1,385
May	1.66	2,349	2.24	1,455
June	1.57	2,396	2.09	1,518
July	1.48	2,442	2.13	1,584
Aug.	1.35	2,484	3.05	1,678

*Recovery to July, 1927

Well B

	Oil production		Water production	
Date	Daily	Cumulative	Daily	Cumulative
*Prior		356		
1927				
July	2.93	446		
Aug.	3.44	553		
Sept.	3.20	649		
Oct.	2.92	740		
Nov.	1.97	799	.80	24
Dec.	3.26	900	1.55	72
1928				
Jan.	2.37	973	1.65	123
Feb.	2.18	1,037	1.63	170
March	1.95	1,097	1.23	209
April	1.73	1,149	1.67	259
May	1 09	1,183	2.35	332
June	.87	1,209	1.41	374
July	.51	1,224	1.15	410
Aug.	.50	1,240	2.67	492
Sept.	.59	1,258	2.41	565
Oct.	.45	1,272	2.08	629
Nov.	1.15	1,306	2.15	694
Dec.	.96	1,336	2.17	761
1929				
Jan.	.62	1,355	2.51	839
Feb.	.24	1,362	2.89	920
March	.34	1,372	3.17	1,018
April	.40	1,384	4.00	1,138
May	.50	1,400	4.50	1,277
June	.50	1,415	4.50	1,412

*Recovery to July, 1927
Abandoned June 29, 1929, to pressure

Table 86. Average daily and cumulative oil and water production of wells C and D in Flood No. 12 by months, in barrels.

Well C

Date	Oil production Daily	Oil production Cumulative	Water production Daily	Water production Cumulative
1927	Prior	336		
July	1.63	386	.65	20
Aug.	1.00	417	.38	32
Sept.	1.45	460	1.10	65
Oct.	1.19	498	1.49	111
Nov.	1.35	538	1.80	165
Dec.	1.22	576	1.88	223
1928				
Jan.	.80	601	2.00	285
Feb.	1.27	638	2.23	350
March	.68	659	2.50	428
April	1.17	694	1.90	485
May	.30	703	1.79	540
June	.33	713	1.08	572
July	.41	726	1.89	631
Aug.	.30	735	3.68	745
Sept.	.29	744	4.00	865
Oct.	.10	747	2.96	957
Nov.	.30	756	2.15	1,021
Dec.	.33	766	2.18	1,089
1929				
Jan.	.24	773	2.62	1,170
Feb.	.12	777	3.05	1,256
March	.29	785	2.47	1,332
April	.21	792	2.89	1,419
May	.10	795	4.18	1,548
June	.10	798	4.50	1,683

Well D

Date	Oil production Daily	Oil production Cumulative	Water production Daily	Water production Cumulative
1928				
May	2.31	72	1.80	56
June	1.03	102	1.54	102
July	1.02	134	2.52	180
Aug.	1.13	169	1.99	242
Sept.	.49	184	1.23	279
Oct.	.30	193	2.26	349
Nov.	.30	202	2.00	409
Dec.	.25	210	1.70	461
1929				
Jan.	.30	219	2.19	529
Feb.	.30	227	3.97	641
March	.30	237	4.53	781
April	.26	245	4.00	901
May	.24	252	4.73	1,048
June	.23	259	5.73	1,219
July	.10	262	6.29	1,414
Aug.	.10	265	9.74	1,716

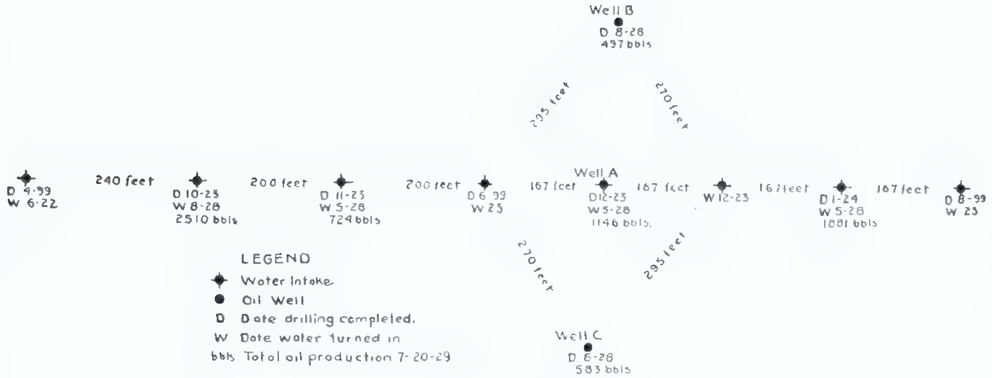


FIGURE 60. **Map of Flood No. 13.**

Flood No. 13

Flood No. 13 is an experimental modified line flood in the southeastern part of the Guffey pool. The spacing of the wells is shown in Figure 60. The Bradford Third sand at this locality is about 25 feet thick and occurs at an average depth of 2,050 feet, so that a maximum pressure of 890 pounds per square inch by hydrostatic head was possible. Only subsurface water entered the intake wells.

Well A produced 1,146 barrels of oil and 3,824 barrels of water during 4⅓ years. Well B produced 497 barrels of oil and 364 barrels of water during the first year and Well C 583 barrels of oil and 1,295 barrels of water during the same period. The flood water from these wells is saltier than that in the Bradford pool, indicating larger quantities of connate water in the sand.

Intensive Floods.

Flood No. 14

Flood No. 14, the first successful five-spot operation, is in the northeastern part of the Bradford pool near the head of Oil Valley. A tract of 25 acres, shown in Figure 61, is developed by 20 water intake and 20 oil wells. The distance between water intake and oil wells is about 190 feet. This was varied slightly to make the pattern fit the tract. The water intake wells were completed between April 1927, and May 1928, and the oil wells between August 1927, and July 1928. At first only subsurface water entered the intake wells. In November 1929, a pressure plant was installed on the property and water, thereafter, was admitted at the top of the wells. The water was obtained from wells sunk in the alluvium of Oil Valley. It was not filtered.

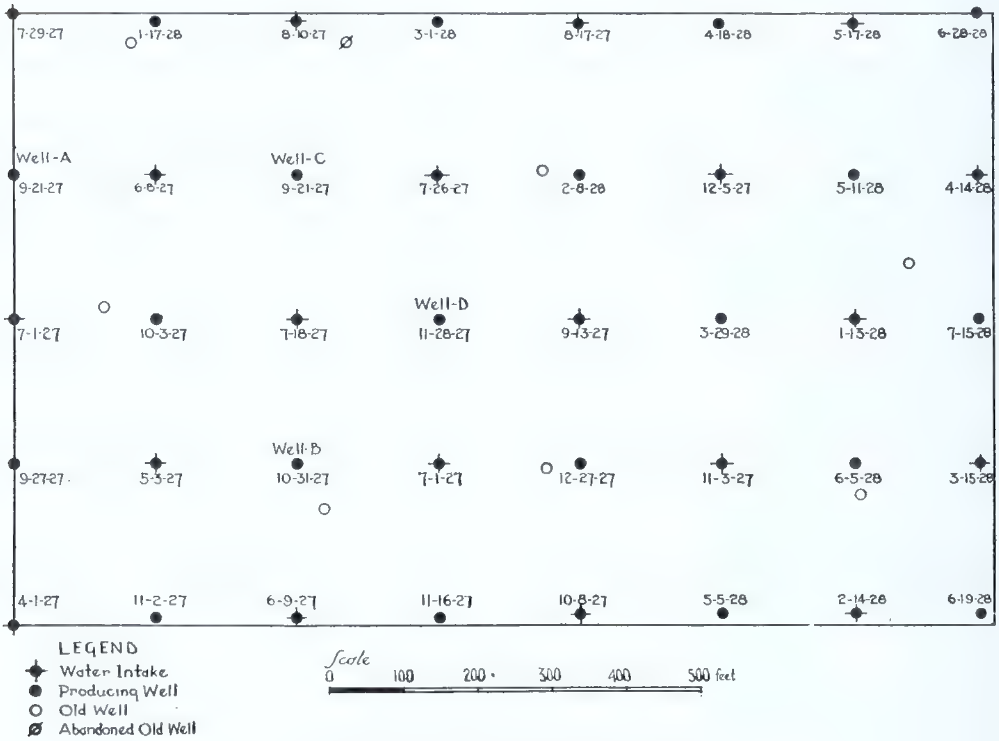


FIGURE 61. Map of Flood No. 14.

From July, 1927, to the end of June, 1935, 169,436 barrels of oil were recovered from the tract, or an average of 6,777 barrels per acre. According to the drillers' records, the sand body has an average thickness of 48 feet. It is estimated that only about 60 percent, or 29 feet, is oil-bearing sandstone, which makes the yield 234 barrels per acre-foot. The total monthly and the cumulative oil and water production are given in Table 87. The former are shown graphically in Figure 62. At the end of June 1935, the operation had almost reached the economic limit. The oil production for each year and the percent this is of the total is given in Table 88. It will be noted that 83.5 percent of the oil was recovered during the first four years and 90 percent during the first five years. Measurement of the water output was stopped at the end of 1931. During the last month that measurements were made, the water output to oil ratio was 12:1. Up to the end of December 1931, it was 3.34:1, at which time 87 percent of the total oil produced to the end of June 1935, had been recovered.

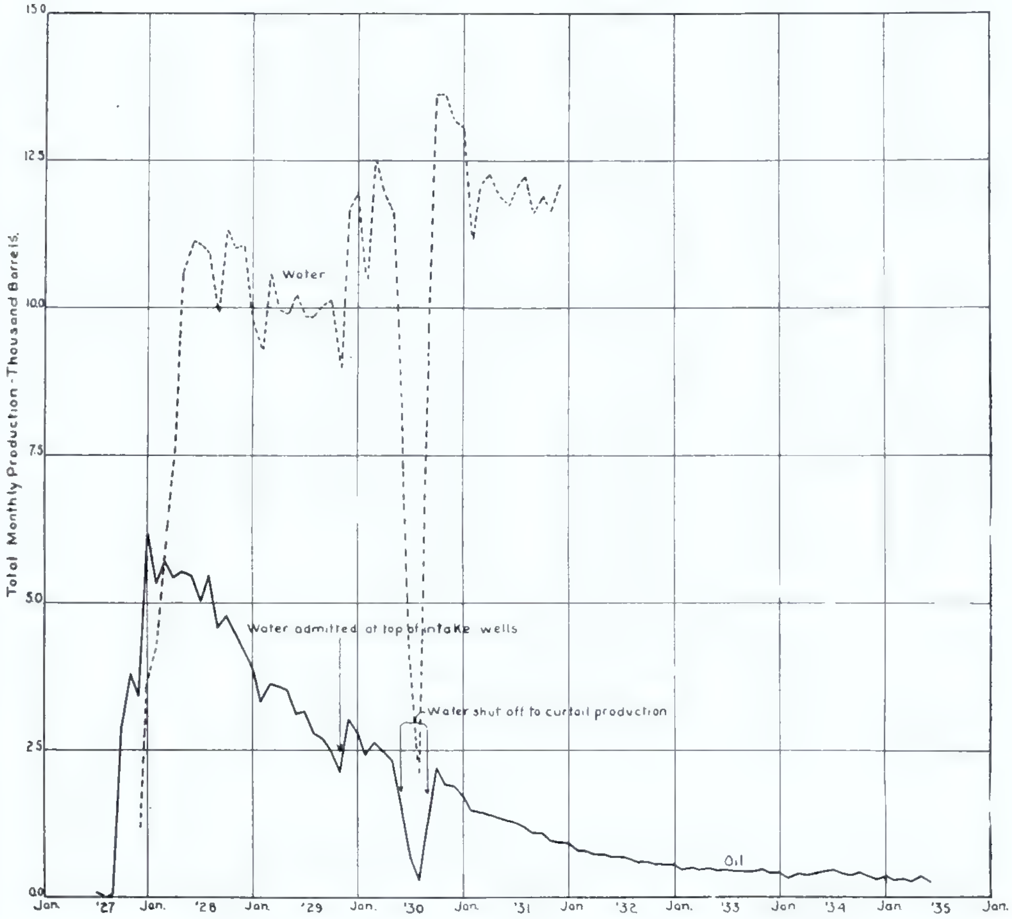


FIGURE 62. Curves showing total monthly oil and water production of Flood No. 14.

Table 87. Total monthly and cumulative oil and water production of Flood No. 14, in barrels.

Date	Oil production		Water production	
	Monthly	Cumulative	Monthly	Cumulative
1927				
July	87	87		
Aug.				
Sept.	82	169		
Oct.	2,885	3,045		
Nov.	3,823	6,877		
Dec.	3,411	10,288	1,205	1,205
1928				
Jan.	6,194	16,482	3,695	4,900
Feb.	5,356	21,838	4,290	9,190
Mar.	5,717	27,555	5,693	14,883
Apr.	5,446	33,001	7,491	22,374
May	5,537	38,538	10,623	32,997
June	5,490	44,028	11,114	44,111
July	5,028	49,056	11,083	55,194
Aug.	5,463	54,519	10,924	66,118
Sept.	4,561	59,080	9,872	75,990
Oct.	4,794	63,874	11,343	87,333
Nov.	4,513	68,387	11,030	98,363
Dec.	4,210	72,597	11,066	109,429
1929				
Jan.	3,893	76,490	9,808	119,237
Feb.	3,331	79,821	9,240	128,277
Mar.	3,625	83,446	10,594	138,871
Apr.	3,576	87,022	9,947	148,818
May	3,544	90,566	9,880	158,698
June	3,136	93,702	10,246	168,944
July	3,178	96,880	9,854	178,798
Aug.	2,805	99,685	9,846	188,644
Sept.	2,710	102,395	10,034	198,678
Oct.	2,516	104,911	10,149	208,827
Nov.	2,159	107,090	8,981	217,808
Dec.	3,046	110,116	11,660	229,468
1930				
Jan.	2,839	112,955	11,965	241,433
Feb.	2,418	115,373	10,422	251,855
Mar.	2,657	118,030	12,531	264,386
Apr.	2,499	120,529	11,947	276,333
May	2,334	122,863	11,630	287,963
June	1,522	124,385	8,424	296,387
July	686	125,071	3,978	300,365
Aug.	285	125,356	2,100	302,465
Sept.	1,307	126,663	9,204	311,669
Oct.	2,231	128,894	13,625	325,294
Nov.	1,940	130,834	13,633	338,927
Dec.	1,901	132,735	13,160	352,087
1931				
Jan.	1,762	134,497	13,073	365,160
Feb.	1,498	135,995	11,109	376,269
Mar.	1.473	137,468	12,098	388.367
Apr.	1,435	138,903	12,270	400,637
May	1,398	140,301	11,906	412,543
June	1,313	141,614	11,761	424,304
July	1,285	142,899	12,028	436,332
Aug.	1,228	144,127	12,261	448,593
Sept.	1,107	145,234	11,588	460,181
Oct.	1,103	146,337	11,902	472,083
Nov.	987	147,324	11,628	483,711
Dec.	960	148,284	12,116	495,827
1932				
Jan.	950	149,234		
Feb.	814	150,048		
Mar.	806	150,854		
Apr.	742	151,596		
May	740	152,336		
June	701	153,037		
July	700	153,737		
Aug.	672	154,409		
Sept.	630	155,039		
Oct.	621	155,660		
Nov.	576	156,236		
Dec.	564	156,800		
1933				
Jan.	570	157,370		
Feb.	492	157,862		
Mar.	524	158,386		
Apr.	497	158,883		
May	504	159,387		
June	480	159,867		
July	478	160,345		
Aug.	470	160,815		
Sept.	454	161,269		
Oct.	451	161,720		
Nov.	499	162,219		
Dec.	428	162,647		
1934				
Jan.	432	163,079		
Feb.	348	163,427		
Mar.	414	163,841		
Apr.	402	164,243		
May	429	164,672		
June	448	165,120		
July	475	165,595		
Aug.	423	166,018		
Sept.	381	166,399		
Oct.	431	166,830		
Nov.	373	167,203		
Dec.	314	167,517		
1935				
Jan.	364	167,881		
Feb.	304	168,185		
Mar.	320	168,505		
Apr.	275	168,780		
May	372	169,152		
June	284	169,436		

Table 88. Oil production by years of Flood No. 14 and yearly percent.

Year	Oil production (barrels)	Percent of total	Year	Oil production (barrels)	Percent of total
1	44,028	26.0	5	11,423	6.7
2	49,674	29.3	6	6,830	4.3
3	30,683	18.1	7	5,728	3.3
4	17,229	10.1	8	3,841	2.2

The top of the Bradford Third sand occurs at an average depth of 1,443 feet on the tract. A maximum pressure by hydrostatic head of about 625 pounds per square inch was, therefore, possible during the interval that subsurface waters entered the intake wells. The water plant, which was started in November 1929, operated at first at a pressure of 200 pounds, which gave

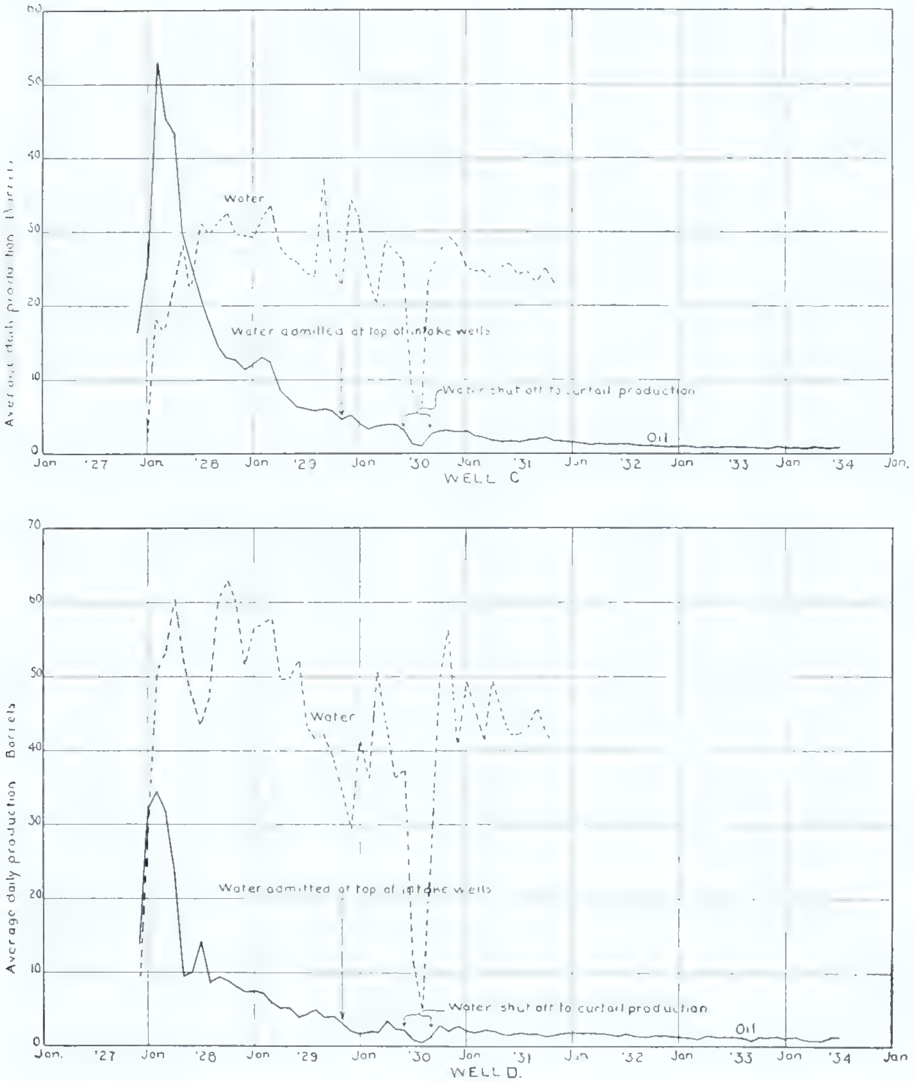


FIGURE 63. Curves showing average daily oil and water production by months of two wells in Flood No. 14.

a pressure of 765 pounds per square inch at the face of the sand. The change in the method of introducing the water and the increase in pressure raised the average daily production of oil per well from 4.06 barrels in October to 4.91 barrels in December 1929. The average water output increased from 16.37 to 18.81 barrels per well. The increase in oil production was almost entirely from the wells on the higher part of the property which probably had received an insufficient supply of subsurface water. These wells also were completed last.

The water plant was shut down between June and September, 1930 in order to curtail production. When it was started again, the pressure was raised to 325 pounds during the first month. One year later it was increased to 350 pounds and two years later to 400 pounds.

During November 1931, the water input amounted to 59,447 barrels. Only 18 of the 20 intake wells were used, so that the average input per well per day was 110 barrels. The pressure at the plant was 350 pounds. As shown in Figure 61, 11 of the 20 intake wells are around the outside boundaries of the tract. If it is assumed that the water is distributed equally among the four quadrants about each intake well, only 83.75 percent can be assigned to oil wells on the tract. This amounts to 49,787 barrels. The total oil and water output of the tract during November 1931, however, was only 12,615 barrels. In other words, after 4½ years of operation, large volumes of water were still being injected into the sand that were not accounted for in the output. Water is either escaping around the packers in the intake wells or else moving through the more permeable parts of the sand onto adjacent tracts.

The total oil and water production of four of the wells in Flood No. 14 is shown in Table 89 for the period that records of individual wells were kept. The average daily and the cumulative production of two of these wells by months is given in Table 90. Curves for the average daily production are shown in Figure 63. It will be noted that well A, a line well with only a three-way drive acting upon it, had a total production equal to only one-half of the average production of wells B, C, and D. A slight complication existed in the area drained by well C in that some water had already entered the sand through an old near-by well, but it is questionable whether any appreciable quantity of oil had been pushed over onto the area from the outside, although, no doubt, a bank of oil had accumulated in the area ahead of the water. Wells C and D had reached such an advanced stage in their production history when the change in the method of introducing the water into the sand was made that this had practically no effect on their production.

Table. 89. Total oil and water production of four wells in Flood No. 14, in barrels.

Well	Oil to July 13, 1934	Oil to end of Nov. 1931	Water to end of Nov. 1931	Water to oil ratio to end of Nov. 1931
A	6,146	5,632	15,612	2.8
B	9,378	8,432	36,830	4.4
C	15,699	14,669	36,156	2.5
D	11,029	9,666	63,729	6.6

Table 90. Average daily and cumulative oil and water production of wells C and D in Flood No. 14 by months, in barrels.

Well C

Date	Oil production Daily	Oil production Cumulative	Water production Daily	Water production Cumulative
1927				
Dec.	16.94	525		
1928				
Jan.	25.24	1,307	1.35	42
Feb.	53.00	2,844	18.00	564
Mar.	45.58	4,257	16.27	1,068
Apr.	43.29	5,556	22.13	1,732
May	30.09	6,489	28.44	2,614
June	25.20	2,245	21.90	3,271
July	21.42	7,909	31.20	4,238
Aug.	17.88	8,463	29.88	5,164
Sept.	14.52	8,899	31.50	6,109
Oct.	13.17	9,307	32.64	7,121
Nov.	12.75	9,690	29.76	8,014
Dec.	11.52	10,047	29,52	8,929
1929				
Jan.	12.00	10,418	29.29	9,837
Feb.	12.99	10,782	31.81	10,728
Mar.	12.40	11,166	33.71	11,773
Apr.	8.54	11,423	27.97	12,612
May	7.52	11,656	26.60	13,437
June	6.31	11,846	25.98	14,217
July	6.01	12,033	24.33	14,972
Aug.	5.91	12,217	24.02	15,717
Sept.	6.03	12,397	37.41	16,839
Oct.	5.87	12,594	25.08	17,623
Nov.	4.47	12,708	22.55	18,299
Dec.	5.21	12,869	34.54	19,370
1930				
Jan.	4.13	12,998	31.89	20,359
Feb.	3.23	13,089	24.41	21,042
Mar.	3.81	13,207	20.66	21,664
Apr.	4.01	13,327	29.03	22,535
May	4.01	13,452	27.57	23,390
June	3.45	13,555	26.16	24,175
July	1.26	13,594	8.68	24,444
Aug.	.89	13,621	6.38	24,642
Sept.	2.73	13,703	24.19	25,367
Oct.	3.14	13,801	27.09	26,207
Nov.	3.18	13,896	29.45	27,090
Dec.	2.98	13,988	28.26	27,967
1931				
Jan.	3.00	14,081	25.33	28,752
Feb.	2.37	14,148	24.55	29,440
Mar.	2.12	14,214	24.73	30,207
Apr.	1.96	14,272	23.56	30,917
May	1.69	14,325	25.19	31,698
June	1.73	14,377	25.67	32,468
July	1.62	14,427	24.28	33,220
Aug.	1.97	14,488	24.77	33,988
Sept.	1.96	14,547	23.25	34,686
Oct.	2.14	14,613	25.13	35,465
Nov.	1.85	14,669	23.04	36,156
Dec.	1.68	14,721		
1932				
Jan.	1.62	14,771		
Feb.	1.54	14,815		
Mar.	1.25	14,854		
Apr.	1.46	14,898		
May	1.34	14,940		
June	1.31	14,979		
July	1.32	15 020		
Aug.	1.21	15,058		
Sept.	1.16	15,092		
Oct.	1.13	15,128		
Nov.	1.13	15,161		
Dec.	1.05	15,194		
1933				
Jan.	1.08	15 228		
Feb.	1.08	15,258		
Mar.	.98	15,288		
Apr.	.99	15,318		
May	.92	15,346		
June	.97	15,376		

	Oil production Daily	Oil production Cumulative
1933		
July	.96	15,405
Aug.	.95	15,434
Sept.	.91	15,462
Oct.	.89	15,489
Nov.	.79	15,513
Dec.	.96	15,543
1934		
Jan.	.90	15,571
Feb.	.79	15,593
Mar.	.77	15,617
Apr.	.79	15,641
May	.80	15,666
June	.74	15,688
July	.86	15,699
(13 days)		

Well D

Date	Oil production Daily	Oil production Cumulative	Water production Daily	Water production Cumulative
1927				
Dec.	13.99	434	9.29	288
1928				
Jan.	32.19	1,432	29.78	926
Feb.	34.43	2,430	50.98	2,405
Mar.	31.96	3,421	53.25	4,055
Apr.	23.62	4,130	60.77	5,878
May	9.58	4,427	52.55	7,507
June	10.12	4,730	47.26	8,925
July	14.36	5,175	43.56	10,276
Aug.	8.55	5,440	47.76	11,756
Sept.	9.54	5,726	60.72	13,578
Oct.	8.97	6,005	63.06	15,533
Nov.	8.19	6,250	59.73	17,324
Dec.	7.58	6,485	51.45	18,919
1929				
Jan.	7.60	6,721	56.60	20,674
Feb.	7.28	6,925	57.05	22,271
Mar.	6.06	7,112	57.86	24,065
Apr.	5.23	7,269	49.67	25,555
May	5.27	7,433	49.74	27,097
June	4.01	7,553	52.12	28,661
July	4.44	7,691	42.94	29,991
Aug.	5.13	7,850	41.46	31,277
Sept.	4.07	7,972	42.27	32,545
Oct.	4.26	8,104	39.07	33,756
Nov.	3.22	8,200	34.41	34,789
Dec.	2.20	8,269	29.38	35,699
1930				
Jan.	1.89	8,326	41.23	36,977
Feb.	2.09	8,385	36.22	38,100
Mar.	1.98	8,446	50.69	39,672
Apr.	3.60	8,554	43.74	40,984
May	2.40	8,629	36.14	42,104
June	2.78	8,712	37.31	43,224
July	.95	8,742	11.85	43,591
Aug.	.66	8,762	5.03	43,747
Sept.	1.33	8,801	24.58	44,844
Oct.	3.01	8,896	49.97	46,034
Nov.	2.24	8,962	56.35	47,724
Dec.	2.81	9,050	40.36	48,975
1931				
Jan.	2.23	9,119	49.29	50,503
Feb.	1.98	9,175	45.26	51,770
Mar.	2.31	9,246	41.14	53,046
Apr.	2.13	9,310	49.36	54,526
May	1.69	9,362	44.81	55,915
June	1.64	9,412	42.32	57,185
July	1.75	9,466	42.35	58,498
Aug.	1.74	9,519	43.08	59,833
Sept.	1.76	9,572	45.70	61,204
Oct.	1.35	9,614	42.11	62,510
Nov.	1.72	9,666	40.62	63,729
Dec.	1.89	9,724		
1932				
Jan.	2.01	9,786		
Feb.	1.91	9,841		
Mar.	1.76	9,896		
Apr.	1.77	9,949		
May	1.68	10,002		
June	1.53	10,048		
July	1.81	10,104		
Aug.	1.58	10,153		
Sept.	1.39	10,194		
Oct.	1.45	10,239		
Nov.	1.44	10,283		
Dec.	1.44	10,327		
1933				
Jan.	1.41	10,371		
Feb.	1.36	10,409		
Mar.	1.08	10,443		
Apr.	1.55	10,489		
May	1.41	10,533		
June	1.36	10,574		

	Oil production Daily	Oil production Cumulative
1933		
July	1.34	10,616
Aug.	1.24	10,653
Sept.	.84	10,679
Oct.	1.27	10,716
Nov.	1.24	10,756
Dec.	1.43	10,800
1934		
Jan.	1.19	10,837
Feb.	1.32	10,874
Mar.	1.15	10,909
Apr.	1.05	10,941
May	.96	10,971
June	1.39	11,012
July	1.28	11,029
(13 days)		

In order to curtail production on this property, the pressure at the water plant was reduced to 150 pounds on May 17, 1930 and the plant was shut down completely on June 30. Operations were resumed September 12. During this shut-down, the water was pumped off and only part of the oil in the producing wells. An examination of Table 87 and Figure 62 shows that about 5,000 barrels of oil were sacrificed during this interval. The decline curve gives no indication that this quantity of oil was recovered after normal operations were resumed, in addition to the anticipated amount at that stage of the flood's progress.

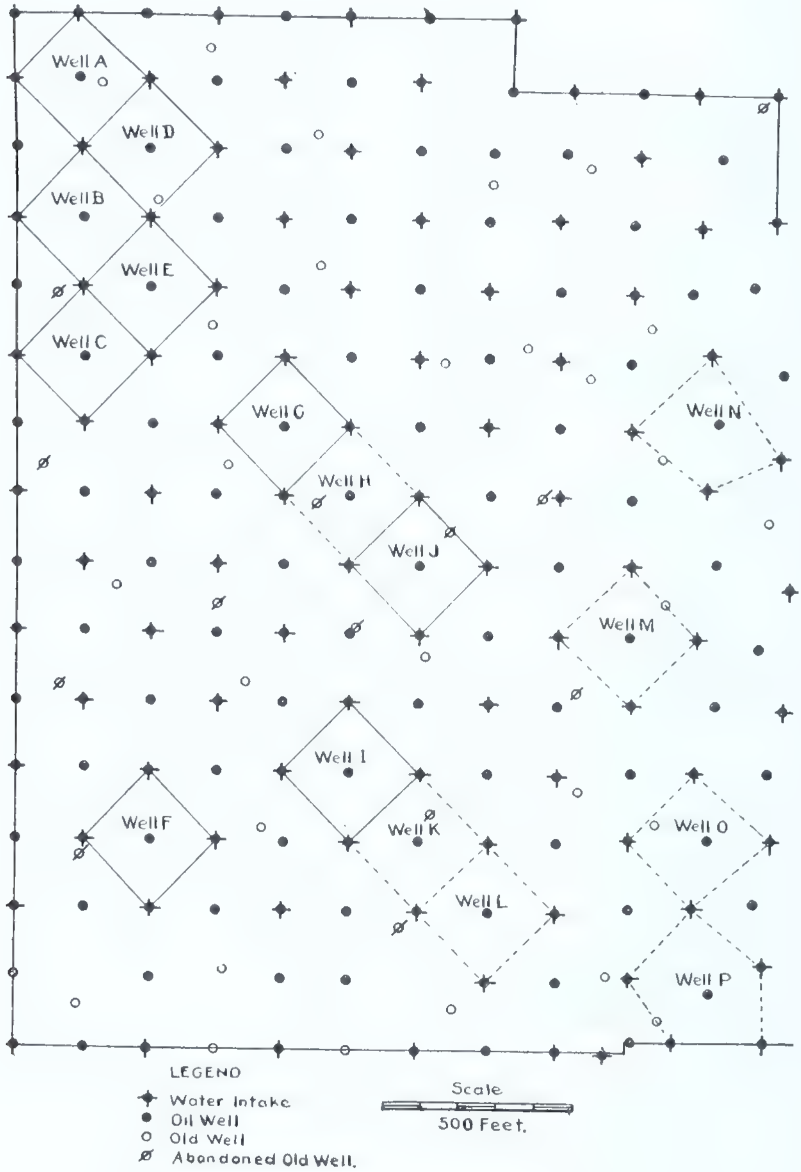


FIGURE 64. Map of Flood No. 15.

Flood No. 15

Flood No. 15 is an extensive five-spot development started in June 1928 in the northeastern part of the Bradford pool, north of Summit. The parts of the flood whose production is discussed are shown in Figure 64. The distance between water intake and oil wells is 180 feet except where necessary to adjust the pattern to boundaries and old circle floods. At first, water for flooding was obtained from wells in a valley on the property. It was not filtered. The water at the plant was given sufficient pump pressure to lift it to the top of the highest well. This gave a pressure of approximately 800 pounds per square inch at the face of the sand. During May 1930, an additional pressure of 50 pounds was applied. In March 1932, this was raised to 200 pounds, in July reduced to 150 pounds, and in August to 70 pounds. In January 1933, it was again raised to 150 pounds and then reduced to 110 pounds in February, and to 80 pounds in June, at which it has been held since. During the first two years of operation, the local water supply proved inadequate. After the Reclamation Supply Corporation's water line reached the property, however, enough additional water was purchased to give each intake well its full quota.

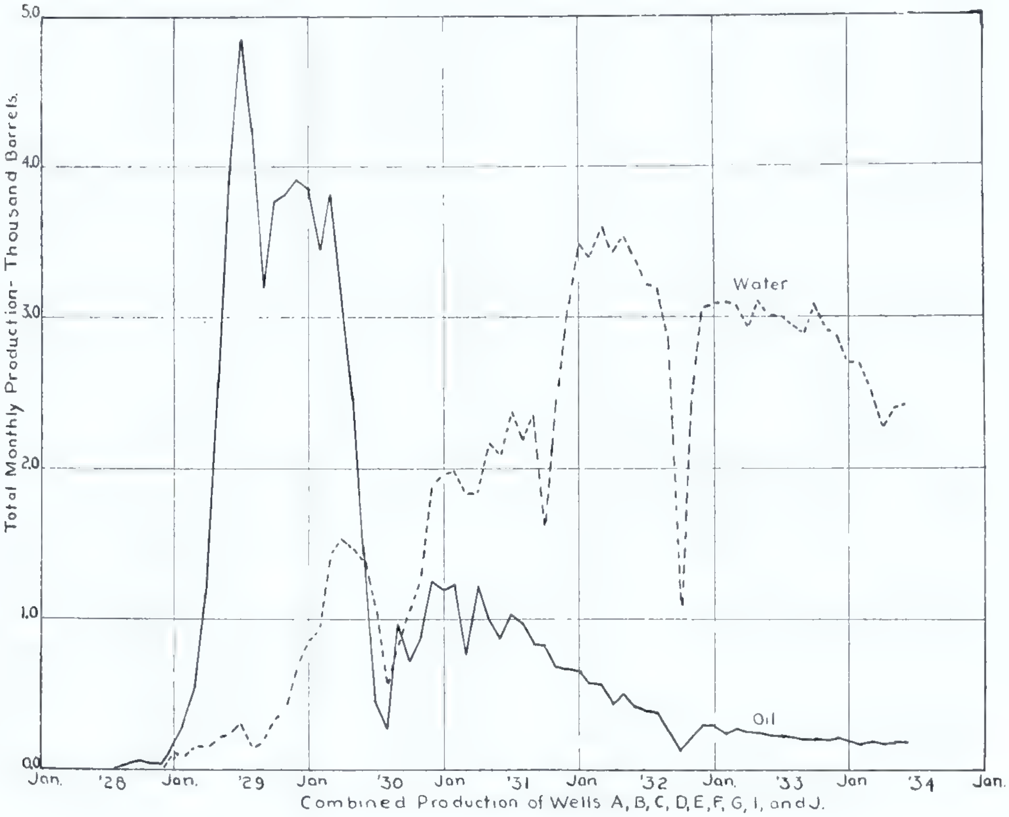


FIGURE 65. Curves showing total monthly oil and water production of wells A, B, C, D, E, F, G, I, and J in Flood No. 15.

Table 91. Average daily oil and water production per well and the monthly and cumulative production of Wells A, B, C, D, E, F, G, I and J in Flood No. 15, in barrels.

		Oil				Water		
Date	Wells	Daily	Monthly	Cumulative	Date	Daily	Monthly	Cumulative
1928					1928			
Aug.	2	.18	11	11				
Sept.	6	.22	39	50	Sept.	.02	1	1
Oct.	7	.25	54	104	Oct.	.02	5	6
Nov.	7	.24	50	154	Nov.	.01	2	9
Dec.	7	.21	45	199	Dec.	.03	7	16
1929					1929			
Jan.	7	.69	152	351	Jan.	.59	130	146
Feb.	8	1.34	299	650	Feb.	.38	89	235
Mar.	9	2.26	631	1,281	Mar.	.58	158	393
Apr.	9	4.43	1,195	2,476	Apr.	.57	155	548
May	9	9.19	2,563	5,039	May	.81	245	773
June	9	14.67	3,960	8,999	June	.90	243	1,016
July	9	17.39	4,853	13,851	July	1.13	315	1,331
Aug.	9	15.32	4,275	18,126	Aug.	.54	146	1,477
Sept.	9	11.91	3,215	21,341	Sept.	.67	183	1,660
Oct.	9	13.51	3,768	25,109	Oct.	1.22	341	2,001
Nov.	9	14.10	3,806	28,915	Nov.	1.51	408	2,409
Dec.	9	14.04	3,918	32,832	Dec.	2.43	680	3,089
1930					1930			
Jan.	9	13.89	3,874	36,707	Jan.	3.05	850	3,939
Feb.	9	13.54	3,413	40,120	Feb.	3.75	947	4,886
Mar.	9	13.65	3,808	43,927	Mar.	5.11	1,428	6,313
Apr.	9	11.72	3,168	47,092	Apr.	5.68	1,535	7,848
May	9	8.88	2,477	49,570	May	5.26	1,469	9,317
June	9	5.49	1,482	51,052	June	5.11	1,381	10,698
July	9	1.65	461	51,513	July	3.84	1,073	11,771
Aug.	9	1.00	278	51,791	Aug.	1.99	556	12,327
Sept.	9	3.60	972	52,763	Sept.	3.05	825	13,152
Oct.	9	2.54	708	53,471	Oct.	3.75	1,047	14,199
Nov.	9	3.25	878	54,349	Nov.	4.68	1,265	15,464
Dec.	9	4.52	1,262	55,611	Dec.	6.78	1,892	17,356
1931					1931			
Jan.	9	4.49	1,199	56,810	Jan.	7.05	1,968	19,324
Feb.	9	4.89	1,234	58,044	Feb.	7.89	1,988	21,312
Mar.	9	2.72	760	58,804	Mar.	6.59	1,838	23,150
Apr.	9	4.54	1,227	60,030	Apr.	6.79	1,831	24,981
May	9	3.57	996	61,027	May.	7.79	2,176	27,157
June	9	3.22	868	61,895	June	7.76	2,095	29,252
July	9	3.79	1,040	62,936	July	8.54	2,382	31,634
Aug.	9	3.50	977	63,913	Aug.	7.97	2,188	33,822
Sept.	9	3.10	838	64,751	Sept.	5.43	2,367	36,189
Oct.	9	2.98	831	65,582	Oct.	8.71	1,619	37,808
Nov.	9	2.54	686	66,269	Nov.	10.31	2,476	40,285
Dec.	9	2.40	668	66,937	Dec.	10.99	3,068	43,353
1932					1932			
Jan.	9	2.36	658	67,596	Jan.	12.49	3,487	46,839
Feb.	9	2.21	577	68,172	Feb.	13.01	3,397	50.237
Mar.	9	2.03	567	68,739	Mar.	12.91	3,603	53,840
Apr.	9	1.81	449	69,188	Apr.	12.67	3,421	57,261
May	9	1.81	505	69,693	May	12.71	3,545	60,806
June	9	1.57	424	70,117	June	12.51	3,378	64,185
July	9	1.40	391	70,508	July	11.54	3,220	67,404
Aug.	9	1.36	380	70,888	Aug.	11.47	3,199	70,603
Sept.	9	.98	266	71,154	Sept.	10.59	2,857	73,460
Oct.	9	1.37	127	71,281	Oct.	8.65	1,076	74,536
Nov.	9	1.05	220	71,502	Nov.	10.38	2,492	77.028
Dec.	9	1.08	300	71,802	Dec.	10.98	3,065	80,093
1933					1933			
Jan.	9	1.06	294	72,096	Jan.	11.07	3,088	83,181
Feb.	9	1.35	250	72,346	Feb.	11.94	3,099	86.281
Mar.	9	.98	273	72 620	Mar.	11.07	3,088	89,369
Apr.	9	.95	256	72,876	Apr.	10.89	2,942	92,311
May	9	.90	251	73,125	May	11.81	3,114	95,424
June	9	.87	234	73,360	June	11.13	3,005	98,429
July	9	.83	231	73,591	July	10.77	3,005	101,434
Aug.	9	.78	219	73,809	Aug.	10.52	2,935	104,370
Sept.	9	.79	213	74,022	Sept.	10.73	2,900	107,269
Oct.	9	.76	212	74.234	Oct.	11.09	3,092	110,362
Nov.	9	.75	203	74,437	Nov.	10.80	2,917	113,279
Dec.	9	.78	218	74,655	Dec.	10.32	2,878	116,157
1934					1934			
Jan.	9	.72	200	74,855	Jan.	9.63	2,687	118,844
Feb.	9	.72	181	75,036	Feb.	10 70	2,695	121,539
Mar.	9	.70	195	75,231	Mar.	10.15	2,517	124,056
Apr.	9	.66	179	75,410	Apr.	9.47	2,273	126,329
May	9	.67	186	75,596	May	9.67	2,398	128,727
June	9	.67	181	75,777	June	10.03	2,422	131,149

During the first six years, the nine wells designated by the letters A, B, C, D, E, F, G, I, and J, in Figure 64, yielded 75,777 barrels of oil. Each well drains an area of 1.49 acres. This, therefore, represents an average yield of 5,651 barrels per acre. According to the drillers' records, the sand body has an average thickness of 73 feet. Two cores taken in the area show that only about 52 percent, or 38 feet is oil-bearing sandstone. The yield per acre-foot during the above period, therefore, was 149 barrels. At the end of this period, the average daily production per well was .67 barrels of oil and 10.03 barrels of water, making the water output to oil ratio 15:1. The water output to oil ratio for the entire period was 1.73:1. The wells are approaching the economic limit so that the additional production obtained from them will not greatly alter the above figures. The intake wells were completed between June 1928 and January 1929, and the oil wells between August 1928 and February 1929. Production was curtailed at intervals between May 1930 and April 1932.

The average daily oil and water production per well and the total monthly and cumulative production for the nine wells is given in Table 91. The total monthly oil and water production is shown graphically by curves in Figure 65. The fluctuations prior to May 1930 were due to shortage of water and between May 1930 and April 1932 to curtailment of production. The oil production for each year and the percent this is of the total for the entire period is given in Table 92.

Table 92. Oil production by years of wells A, B, C, D, E, F, G, I, and J in Flood No. 15 and percent this represents of total for entire period.

Year	Oil production (barrels)	Percent of total
1	13,852	18.2
2	37,661	49.7
3	11,423	15.1
4	7,572	10.0
5	3,083	4.1
11 months	2,186	2.9

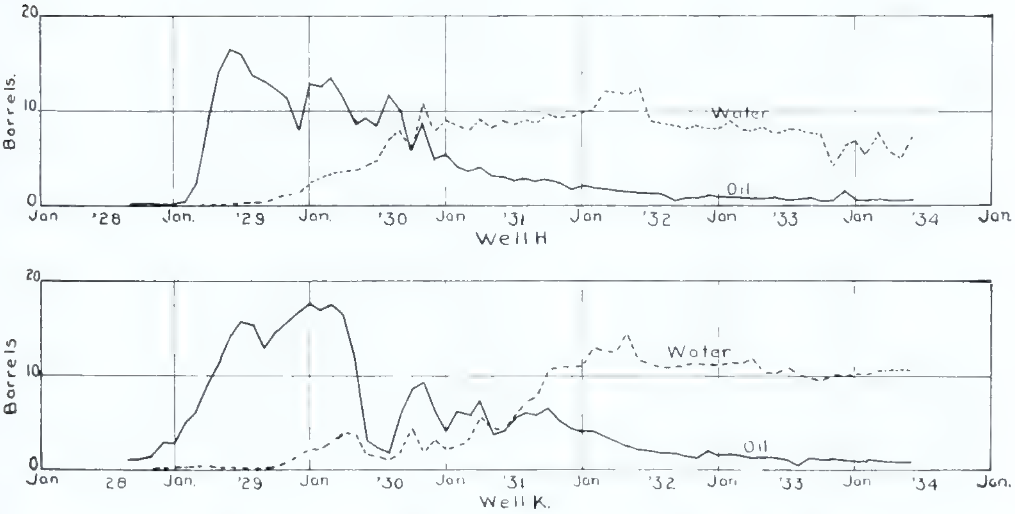


Figure 66. Curves showing average daily oil and water production by months of wells H and K in Flood No. 15.

Between May 1930 and April 1932, when proration was in effect, water was admitted to the intake wells as usual, but only the flood water was pumped from the producing wells each day, the oil being allowed to rise in the wells. The back pressure thus built up was very effective in cutting down production. During this period, well H was operated as usual in order to have a standard of comparison for the performance of the curtailed wells.

The average daily and cumulative oil and water production by months for well H is given in Table 93 and the former is shown graphically in Figure 66. The well yielded at the rate of 6,268 barrels per acre in contrast to the average of 5,651 barrels for the nine wells already discussed. For the entire period its water output to oil ratio was 1.39:1 as compared to 1.73:1 for the nine wells, and at the end of that period it still had an average daily output of .71 barrels of oil and a water output to oil ratio of only 10:1 as compared to .67 barrels and a ratio of 15:1 for the nine wells.

Wells G and J to the northwest and southeast of it, respectively, had an average yield of only 5,495 barrels per acre and a water output to oil ratio of 1.63:1. The two wells to the northeast and southwest, respectively, however, had the same average yield as well H when taken together and the one to the southwest exceeded it slightly. The production of well H was about 5 percent greater than the average of the group of nine wells, of which it is the central one.

Several adverse operating conditions probably affected the well. The pumpers occasionally forgot that its production was not to be curtailed. Also the water intake at the east corner of the unit was shut off permanently in February 1932. This probably did not affect the final result very much as 87 per cent of its total production had already been obtained. In favor of the well, of course, was the fact that when the other wells were being curtailed, it occupied an area of lower pressure toward which fluids would tend to move.

Although the difference in yield between well H and the others is not large enough alone to warrant any very definite conclusion, when considered with the trend of the production curves, the evidence seems to indicate that appreciable amounts of oil were lost through curtailment. If this oil is being recovered as deferred production in the later stages of the operation, it is being done in driblets along with large volumes of water, which makes the operation expensive.

Well K is the largest producer of the group shown in Figure 64. Its average daily yield and cumulative production by months are given in Table 93 and the former is shown graphically in Figure 66. The reason for its behaviour is due to the fact that the well is north of an old circle flood which, apparently, had shoved a bank of oil over onto the area which the well drains.

This well and an old well nearby, between September 1928, and June 1934, produced 12,960 barrels of oil and 13,974 barrels of water, a recovery of 8,698 barrels per acre. It has 36.5 feet of oil-bearing sandstone, which makes the yield 238 barrels per acre-foot. Core 9, taken from well K, showed an oil content equivalent to 17,535 barrels per acre. This would indicate a 50 percent recovery. In June 1934, the well still had an average daily production of 1.05 barrels of oil with a water output to oil ratio of 10:1. Well I, northwest of well K, yielded 6,713 barrels per acre during the same period, also above average, and well L to the southeast yielded only 3,713 barrels per acre, which is considerably below average.

Table 93. Average daily and cumulative oil and water production of wells H and K in Flood No. 15 by months, in barrels.

Well H

Date	Oil production		Water production	
	Daily	Cumulative	Daily	Cumulative
1928				
Sept.	.35	10		
Oct.	.26	19	.01	
Nov.	.23	26	.01	
Dec.	.24	33	.02	1
1929				
Jan.	.21	40	.01	2
Feb.	.47	53	.08	4
Mar.	2.43	128	.14	8
Apr.	8.39	380	.05	10
May	14.26	822	.07	12
June	16.44	1,315	.08	15
July	16.08	1,814	.19	21
Aug.	13.71	2,239	.34	31
Sept.	13.24	2,636	.35	42
Oct.	12.31	3,018	.83	68
Nov.	11.55	3,364	1.21	104
Dec.	7.92	3,610	1.38	147
1930				
Jan.	12.85	4,008	2.44	223
Feb.	12.65	4,362	3.01	307
Mar.	13.59	4,784	3.53	417
Apr.	11.77	5,137	3.67	527
May	8.74	5,408	3.89	648
June	9.23	5,685	4.18	773
July	8.41	5,946	4.91	925
Aug.	11.73	6,309	7.07	1,143
Sept.	10.12	6,613	8.02	1,184
Oct.	5.71	6,790	5.95	1,568
Nov.	8.82	7,055	10.84	1,893
Dec.	5.14	7,214	7.84	2,137
1931				
Jan.	5.39	7,381	9.13	2,420
Feb.	4.35	7,503	8.56	2,659
Mar.	3.75	7,619	7.94	2,906
Apr.	4.09	7,740	9.19	3,181
May	3.23	7,841	8.37	3,441
June	3.14	7,935	8.92	3,709
July	2.76	8,020	8.67	3,977
Aug.	2.94	8,112	9.14	4,261
Sept.	2.65	8,191	8.75	4,523
Oct.	2.79	8,278	9.76	4,826
Nov.	2.45	8,352	9.38	5,107
Dec.	1.70	8,404	9.52	5,403
1932				
Jan.	2.17	8,472	9.97	5,712
Feb.	1.95	8,528	10.33	6,011
Mar.	1.79	8,583	12.16	6,388
Apr.	1.61	8,632	12.00	6,748
May	1.54	8,680	11.82	7,115
June	1.45	8,723	12.54	7,491
July	1.35	8,765	9.00	7,770
Aug.	1.29	8,805	8.65	8,038
Sept.	.54	8,821	8.42	8,291
Oct.	.84	8,847	8.15	8,543
Nov.	.87	8,874	8.42	8,796
Dec.	1.17	8,910	8.15	9,048
1933				
Jan.	.90	8,938	8.15	9,301
Feb.	.91	8,963	9.02	9,554
Mar.	.91	8,991	8.15	9,806
Apr.	.92	9,019	7.97	10,045
May	.86	9,046	8.32	10,303
June	.83	9,070	7.63	10,542
July	.69	9,092	8.15	10,795
Aug.	.76	9,115	8.15	11,048
Sept.	.81	9,140	7.62	11,276
Oct.	.70	9,161	7.62	11,513
Nov.	.69	9,182	4.38	11,644
Dec.	.82	9,207	6.36	11,841
1934				
Jan.	.78	9,232	6.90	12,055
Feb.	.75	9,252	5.42	12,207
Mar.	.76	9,276	7.81	12,449
Apr.	.67	9,296	5.63	12,618
May	.70	9,318	5.08	12,775
June	.71	9,339	7.44	12,998

Well K

Date	Oil production		Water production	
	Daily	Cumulative	Daily	Cumulative
1928				
Sept.	1.12	33		
Oct.	1.17	70	.02	
Nov.	1.51	115	.13	4
Dec.	2.89	205	.25	12
1929				
Jan.	2.89	322	.27	21
Feb.	4.86	458	.15	25
Mar.	6.30	653	.27	33
Apr.	9.12	927	.31	42
May	11.25	1,276	.19	48
June	14.18	1,701	.21	54
July	15.69	2,187	.13	59
Aug.	15.44	2,666	.06	61
Sept.	12.84	3,051	.11	64
Oct.	14.78	3,502	.31	73
Nov.	15.64	3,971	.90	100
Dec.	16.75	4,491	1.59	150
1930				
Jan.	17.65	5,036	2.19	218
Feb.	1691	5,509	2.21	279

Table 93. (Continued)

Date	Oil production		Water production	
	Daily	Cumulative	Daily	Cumulative
Mar.	17.61	6,055	3.12	376
Apr.	16.52	6,551	3.99	496
May	12.09	6,926	3.91	617
June	3.17	7,021	1.64	666
July	2.40	7,095	1.44	711
Aug.	1.93	7,155	.99	742
Sept.	5.81	7,330	1.72	794
Oct.	8.44	7,591	4.46	932
Nov.	9.29	7,876	1.89	988
Dec.	6.14	8,060	3.25	1,089
1931				
Jan.	4.24	8,192	2.03	1,152
Feb.	6.30	8,369	2.46	1,121
Mar.	5.67	8,545	2.89	1,311
Apr.	7.36	8,766	5.62	1,479
May	3.67	8,879	4.40	1,616
June	4.00	9,000	4.06	1,738
July	5.57	9,172	5.96	1,923
Aug.	6.09	9,361	7.08	2,142
Sept.	5.94	9,540	7.74	2,374
Oct.	6.53	9,742	10.73	2,707
Nov.	5.19	9,898	10.83	3,032
Dec.	4.58	10,040	11.01	3,373
1932				
Jan.	4.26	10,172	11.06	3,716
Feb.	4.22	10,294	13.14	4,084
Mar.	3.55	10,404	12.68	4,477
Apr.	3.04	10,496	12.48	4,852
May	2.67	10,579	14.65	5,306
June	2.33	10,649	11.62	5,654
July	2.13	10,715	11.26	6,000
Aug.	1.98	10,776	10.90	6,341
Sept.	1.79	10,830	11.10	6,674
Oct.	1.62	10,880	11.08	7,018
Nov.	1.46	10,924	11.43	7,361
Dec.	2.10	10,989	11.26	7,710
1933				
Jan.	1.70	11,042	11.19	8,054
Feb.	1.65	11,088	11.39	8,373
Mar.	1.59	11,137	11.26	8,722
Apr.	1.48	11,181	11.98	9,079
May	1.46	11,227	10.39	9,401
June	1.43	11,270	10.38	9,713
July	1.21	11,307	10.90	10,051
Aug.	.52	11,323	10.12	10,364
Sept.	1.34	11,363	9.65	10,654
Oct.	1.21	11,401	9.48	10,948
Nov.	1.29	11,439	10.07	11,250
Dec.	1.14	11,475	10.01	11,560
1934				
Jan.	1.06	11,508	10.31	11,880
Feb.	1.13	11,539	10.14	12,164
Mar.	1.11	11,574	10.51	12,490
Apr.	1.01	11,604	10.69	12,810
May	1.04	11,636	10.70	13,142
June	1.05	11,668	10.66	13,462
July	1.11	11,702	10.39	13,784
Aug.	.93	11,731	10.68	14,115
Sept.	.99	11,761	11.04	14,446
Oct.	.97	11,791	9.68	14,746
Nov.	.96	11,820	11.19	15,082
Dec.	1.12	11,855	11.21	15,430
1935				
Jan.	.92	11,883	11.23	15,778
Feb.	.92	11,909	11.40	16,097
Mar.	.96	11,939	11.76	16,462
Apr.	.90	11,966	9.02	16,732
May	.91	11,994	11.72	17,095
June	.91	12,021	9.18	17,463
July	.87	12,048	10.10	17,812
Aug.	.87	12,075	9.74	18,114
Sept.	.89	12,101	11.60	18,462

Fifteen months later the total oil recovery from the K-unit had reached 13,393 barrels and the water production 18,974 barrels. At the end of the latter period, therefore, the yield per acre amounted to 8,988 barrels, and per acre-foot 246 barrels. The daily oil production had dropped to 0.89 barrels and the water output to oil ratio had increased to 13:1. At this stage the recovery is equivalent to 51 percent of the original oil shown by the analysis of core 9.

Wells N, O and P are examples of delayed drilling. Water had been turned into the last of the intake wells by January 1931, but the oil wells were not completed until April 1932. They were not curtailed after production started. The spacing was modified somewhat to fit boundaries. To the end of June 1934, the three wells had produced 29,732 barrels of oil and 28,631 barrels of water, a recovery of 5,807 barrels of oil per acre. The water output to oil ratio during that period was only .96:1. In contrast, the 13 other wells designated by letters in Figure 64, to the end of June, 1934, showed an average recovery of only 5,766 barrels of oil per acre with a water output to oil ratio of 1.66:1.

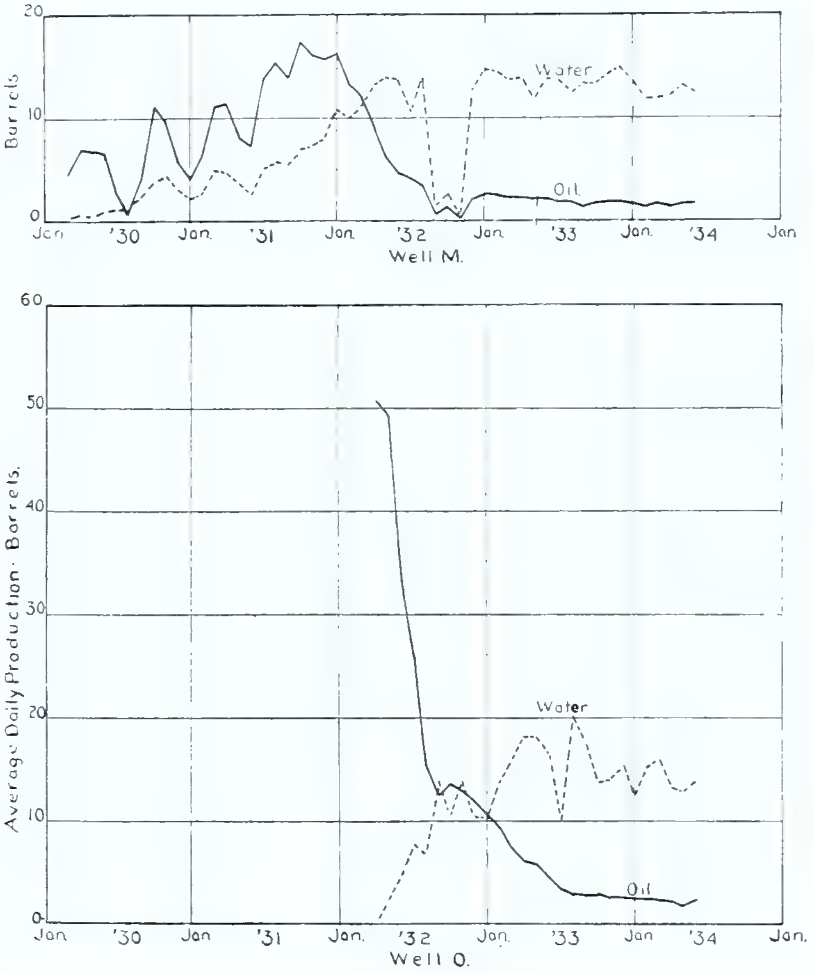
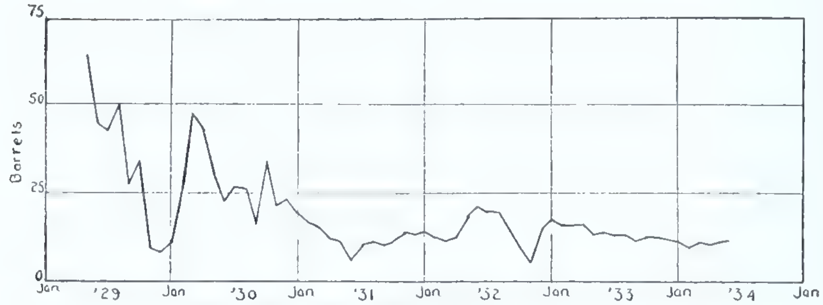
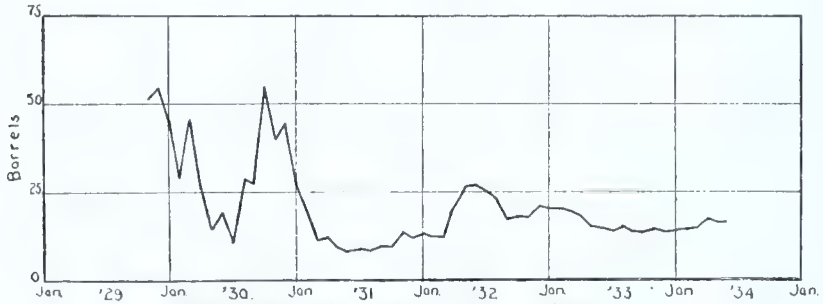


FIGURE 67. Curves showing average daily oil and water production by months of wells M and O in Flood No. 15.

The average daily and cumulative oil and water production of wells M and O and the water input for their respective units by months are given in Tables 94 and 95. The average daily oil and water production by months is shown graphically in Figure 67 and the water input in Figure 68. Well M was operated in the usual manner, but O is one of the delayed wells. By the end of September 1935, well M had produced 9,843 barrels of oil and 18,710 barrels of water, a recovery of 6,606 barrels of oil per acre, with a water output to oil ratio of 1.90:1. During September 1935, the average daily oil production was still .86 barrels with a water output to oil ratio of 13.5:1. Well O, at the end of September 1935, had produced 10,014 barrels of oil and 16,784 barrels of water, a recovery of 6,461 barrels per acre, with a water output to oil ratio of 1.67:1. During September 1935, the well was still yielding an average of 1.26 barrels of oil per day with a water output to oil ratio of 13.8:1.



Average daily water input per well M-Group.



Average daily water input per well O-Group.

FIGURE 68. **Curves showing average daily water input per well for M and O units in Flood No. 15.**

Although the delayed drilling on this particular tract gives no definite indication of an appreciably greater recovery per acre, it has undoubtedly resulted in a saving in operating costs. The same amount of oil is being recovered in much less time and less water accompanies the oil.

Table 94. Average daily and cumulative oil and water production of well M and water input for M-unit in Flood No. 15 by months, in barrels.

Date	Oil production Daily	Oil production Cumulative	Water production Daily	Water production Cumulative	Water input Daily	Water input Cumulative
1930						2,621*
Mar.	4.48	139	.30	9	23.75	3,358
Apr.	7.03	350	.53	25	21.60	4,012
May	6.75	559	.43	38	14.77	4,470
June	6.64	758	.81	63	17.19	4,986
July	2.99	851	1.07	96	20.19	5,612
Aug.	.55	868	1.28	35	13.06	6,017
Sept.	4.31	998	2.35	206	11.96	6,376
Oct.	11.15	1,343	3.76	323	34.08	7,432
Nov.	9.96	1,642	4.34	463	21.44	8,075
Dec.	5.79	1,822	3.14	560	23.53	8,805
1931						
Jan.	4.02	1,946	2.18	628	19.1	9,399
Feb.	6.30	2,123	2.61	701	16.1	9,850
Mar.	11.00	2,464	4.93	854	15.2	10,320
Apr.	11.33	2,803	4.67	994	12.6	10,698
May	8.15	3,056	3.71	1,109	11.6	11,059
June	7.24	3,273	2.56	1,186	6.03	11,240
July	13.84	3,702	5.06	1,343	10.78	11,574
Aug.	15.45	4,181	5.78	1,522	11.26	11,923
Sept.	13.98	4,601	5.53	1,688	7.77	12,156
Oct.	17.52	5,144	6.85	1,900	11.8	12,522
Nov.	16.21	5,630	7.31	2,120	14.0	12,942
Dec.	15.69	6,117	8.08	2,370	13.3	13,353
1932						
Jan.	16.22	6,619	10.94	2,709	14.1	13,791
Feb.	13.31	7,006	9.97	2,998	12.6	14,157
Mar.	12.10	7,381	11.00	3,339	11.6	14,517
Apr.	8.87	7,647	13.10	3,732	12.5	14,893
May	6.24	7,841	13.91	4,163	18.4	15,463
June	4.59	7,978	13.73	4,575	21.4	16,105
July	4.03	8,103	10.63	4,905	19.9	16,724
Aug.	3.51	8,212	14.08	5,341	19.8	17,337
Sept.	.63	8,231	1.33	5,381	14.8	17,782
Oct.	1.24	8,269	2.59	5,462	9.6	18,080
Nov.	.04	8,270	.12	5,465	5.9	18,258
Dec.	2.13	8,336	12.55	5,854	14.6	18,712
1933						
Jan.	2.51	8,404	14.79	6,313	17.6	19,257
Feb.	2.47	8,483	14.55	6,720	15.9	19,694
Mar.	2.32	8,555	13.72	7,145	15.9	20,198
Apr.	2.33	8,625	13.76	7,558	16.0	20,680
May	2.19	8,695	11.83	7,925	13.1	21,085
June	2.12	8,758	13.81	8,339	13.8	21,499
July	1.98	8,819	13.65	8,762	13.1	21,906
Aug.	1.90	8,878	12.57	9,152	13.0	22,310
Sept.	1.40	8,920	13.37	9,553	11.6	22,658
Oct.	1.73	8,974	13.31	9,966	12.8	23,056
Nov.	1.75	9,026	14.29	10,394	12.5	23,432
Dec.	1.76	9,081	15.06	10,861	11.9	23,802
1934						
Jan.	1.65	9,132	13.61	11,283	11.3	24,163
Feb.	1.36	9,171	11.93	11,617	9.8	24,438
Mar.	1,65	9,222	11.99	11,989	11.1	24,783
Apr.	1.50	9,267	12.11	12,352	10.7	25,106
May	1.60	9,316	13.22	12,762	11.2	25,452
June	1.63	9,365	12.54	13,138	11.9	25,810
July	1.39	9,408	10.39	13,529	13.4	26,227
Aug.	1.16	9,444	10.68	13,873	13.4	26,642
Sept.	1.34	9,484	11.04	14,208	11.8	26,996
Oct.	.97	9,514	9.68	14,566	13.6	27,418
Nov.	1.20	9,550	11.19	14,906	13.6	27,826
Dec.	1.13	9,585	11.21	15,271	13.5	28,246
1935						
Jan.	1.27	9,624	11.23	15,594	13.3	28,657
Feb.	.77	9,646	11.40	16,076	13.1	29,024
Mar.	.99	9,677	11.76	16,391	10.7	29,356
Apr.	.95	9,705	9.02	16,770	11.8	29,709
May	1.06	9,738	11.72	17,160	10.7	30,041
June	.89	9,765	9.18	17,534	11.8	30,395
July	.85	9,791	10.10	17,942	13.6	30,815
Aug.	.83	9,817	9.74	18,321	13.8	31,241
Sept.	.86	9,843	11.60	18,710	14.1	31,664

*Prior to Mar., 1930

Table 95. Average daily and cumulative oil and water production of well O and water input for O-unit in Flood No. 15 by months, in barrels.

	Oil production		Water production		Water input	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative
1932						11,211*
Apr.	50.67	1,520	.05	2	20.4	11,824
May	49.31	3,048	2.37	75	26.6	12,649
June	33.53	4,054	4.65	215	27.2	13,467
July	26.50	4,876	7.72	454	25.3	14,252
Aug.	15.61	5,360	7.07	673	23.3	14,976
Sept.	12.47	5,734	13.90	985	17.6	15,504
Oct.	13.63	6,157	10.39	1,307	18.1	16,066
Nov.	12.95	6,545	13.90	1,619	18.0	16,608
Dec.	11.88	6,913	10.39	1,941	21.2	17,265
1933						
Jan.	10.65	7,243	10.39	2,263	20.6	17,903
Feb.	9.37	7,506	13.72	2,647	20.2	18,470
Mar.	7.58	7,741	15.89	3,140	19.7	19,082
Apr.	6.10	7,924	18.15	3,684	18.4	19,635
May	5.83	8,105	18.32	4,253	15.9	20,128
June	4.61	8,243	16.66	4,753	15.0	20,579
July	3.56	8,353	9.83	5,058	14.1	21,016
Aug.	2.95	8,445	20.26	5,686	15.7	21.502
Sept.	2.83	8,530	17.61	6,214	13.8	21,917
Oct.	2.98	8,622	13.82	6,643	13.5	22,338
Nov.	2.56	8,698	14.01	7,063	14.3	22,769
Dec.	2.62	8,779	15.35	7,539	14.0	23,205
1934						
Jan.	2.50	8,858	12.42	7,924	14.1	23,643
Feb.	2.46	8,926	15.13	8,347	14.5	24,050
Mar.	2.40	9,001	16.08	8,846	14.8	24,510
Apr.	2.38	9,072	13.30	9,245	17.7	25,040
May	1.82	9,129	13.07	9,650	16.9	25,565
June	2.41	9,201	13.82	10,065	16.8	26,071
July	2.33	9,273	12.68	10,458	17.6	26,615
Aug.	2.15	9,340	12.48	10,845	17.0	27,144
Sept.	2.08	9,402	14.76	11,288	17.7	27,673
Oct.	1.71	9,455	14.38	11,734	18.3	28,241
Nov.	1.94	9,513	14.78	12,177	18.0	28,781
Dec.	2.77	9,599	13.26	12,588	17.6	29,328
1935						
Jan.	1.83	9,656	14.17	12,027	18.7	29,908
Feb.	1.48	9,697	13.98	13,419	18.8	30,434
Mar.	1.48	9,743	14.37	13,864	18.8	31,018
Apr.	1.66	9,793	14.38	14,296	18.7	31,580
May	1.72	9,846	14.94	14,759	18.1	32,141
June	1.51	9,892	15.90	15,236	19.0	32,710
July	1.45	9,937	15.52	15,717	20.0	33,331
Aug.	1.28	9,976	17.57	16,262	18.0	33,888
Sept.	1.26	10,014	17.43	16,784	14.6	34,327

*Prior to Apr. 1932

On the assumption that the water which enters the input wells in a five-spot is distributed equally among the four quadrants about the well the water input to oil ratio to the end of September 1935 in the M-unit was 3.22:1 and in the O-unit 3.43:1. The relation of fluid output to input for the B, K, M, and O units during the first nine months of 1934 and 1935 is shown in Table 96. In the M-unit, the water is apparently not uniformly distributed about the intake wells as the output exceeds the input.

Table 96. Relation of fluid output to input in the B, K, M, and O units of Flood No. 15 during the first nine months of 1934 and 1935, in barrels.

Unit	Oil	Water output	Total fluid produced	Water input
1934				
B	117	2,587	2,704	3,053
K	286	2,886	3,172	3,556
M	503	3,347	3,850	3,194
O	622	3,749	4,371	4,468
1935				
B	99	2,970	3,069	4,537
K	247	3,033	3,280	3,318
M	258	3,439	3,696	3,469
O	415	4,196	4,611	5,099

Flood No. 16

Flood No. 16 is part of an intensive flood operation in the Bradford pool south of Summit. The pattern, as shown in Figure 69, is irregular owing to the fact that it had to be adjusted to boundaries and old floods. The wells designated by letters A, B, C and D drain 3.14 acres. To the end of June 1930, these wells had produced 22,846 barrels of oil and 43,072 barrels of water, or an average of 7,276 barrels of oil per acre. The water output to oil ratio for the entire period was 1.89:1. According to the drillers' records, the sand body is 48 feet thick. About 64 percent or 31 feet of this is oil-bearing sandstone, making the yield per acre-foot 235 barrels.

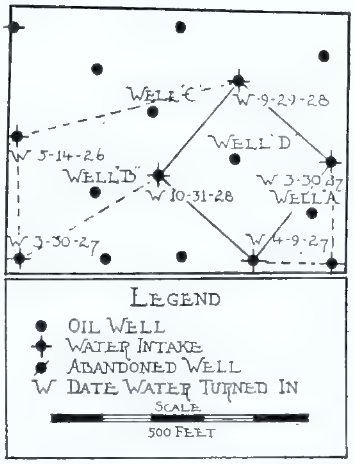


FIGURE 69. Map of Flood No. 16.

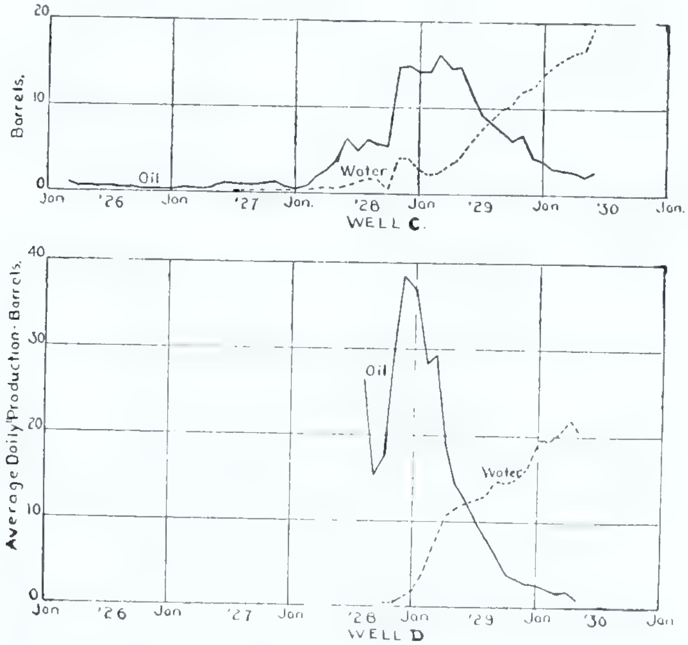


FIGURE 70. Curves showing average daily oil and water production by months of wells C and D in Flood No. 16.

Table 97. Average daily and cumulative oil and water production of wells C and D in Flood No. 16 by months, in barrels.

Well C

Date	Oil Daily	Oil Cumulative	Water Daily	Water Cumulative
1925				
Nov.	.86	26		
1926				
Jan.	1.04	58		
Feb.				
Mar.	1.02	90		
Apr.	.49	104		
May	.50	120		
June	.43	133		
July	.62	152		
Aug.	.50	167		
Sept.	.44	181		
Oct.	.35	191		
Nov.	.30	200		
Dec.	.25	208		
1927				
Jan.	.19	214		
Feb.	.51	228		
Mar.	.42	241		
Apr.	.39	253		
May	.71	275		
June	1.10	308		
July	1.05	341	.05	2
Aug.	.92	369	.06	3
Sept.	.92	397	.07	6
Oct.	1.14	432		
Nov.	1.43	475	.09	8
Dec.	.76	499	.19	14
1928				
Jan.	.38	510		
Feb.	.72	531	.16	19
Mar.	1.75	585	.63	38
Apr.	2.72	667	.68	59
May	3.63	780	.65	79
June	6.36	970	.98	108
July	4.84	1,120	1.39	151
Aug.	6.36	1,318	1.66	203
Sept.	5.80	1,492	1.63	252
Oct.	5.13	1,651	.29	261
Nov.	14.56	2,087	4.25	388
Dec.	14.82	2,547	4.13	516
1929				
Jan.	14.15	2,985	2.84	604
Feb.	14.11	3,381	2.31	669
Mar.	16.12	3,880	2.45	745
Apr.	14.54	4,316	3.31	844
May	14.59	4,769	4.29	977
June	11.84	5,124	6.02	1,158
July	9.44	5,417	7.60	1,393
Aug.	8.26	5,673	8.77	1,665
Sept.	7.28	5,891	9.88	1,961
Oct.	6.29	6,086	10.47	2,286
Nov.	6.96	6,295	11.87	2,642
Dec.	4.32	6,429	12.33	3,025
1930				
Jan.	3.88	6,549	13.94	3,457
Feb.	3.16	6,638	14.91	3,874
Mar.	2.83	6,725	15.65	4,359
Apr.	2.64	6,805	16.40	4,851
May	2.19	6,872	16.76	5,371
June	2.56	6,949	19.49	5,956

Well D

Date	Oil Daily	Oil Cumulative	Water Daily	Water Cumulative
Aug.	26.41	819		
Sept.	15.21	1,275		
Oct.	17.15	1,807	.28	9
Nov.	30.22	2,713	.57	26
Dec.	38.50	3,907	1.26	65
1929				
Jan.	37.12	5,057	2.06	129
Feb.	31.99	5,953	4.08	243
Mar.	29.42	6,865	7.60	479
Apr.	19.13	7,439	10.77	802
May	14.34	7,884	11.52	1,159
June	12.60	8,262	12.22	1,525
July	10.05	8,573	12.49	1,913
Aug.	8.21	8,828	12.93	2,313
Sept.	6.08	9,010	14.82	2,758
Oct.	3.98	9,133	14.64	3,212
Nov.	3.31	9,233	15.05	3,663
Dec.	2.81	9,320	16.19	4,165
1930				
Jan.	2.72	9,404	19.62	4,773
Feb.	2.18	9,465	19.52	5,320
Mar.	1.80	9,521	20.36	5,951
Apr.	1.93	9,579	21.87	6,607
May	1.01	9,610	20.28	7,236

Prior to 1928, the intake wells on this property had been piped for subsurface water only. During 1928, a pressure plant was installed and thereafter the water was introduced at the top. At first an additional pressure of 60 pounds per square inch above that of the hydrostatic head of the highest wells, which amounts to 700 pounds, was used. At the end of eight months, this was boosted to 350 pounds. At the start, 36 water intakes on the property took an average of 200 barrels per day each; three months later, this dropped to 72 barrels; and seven months later, to 50 barrels.

The average daily and cumulative oil and water production of wells C and D by months is given in Table 97. The former is shown graphically in Figure 70. Core 11, whose permeability profile is shown in Plate 17, came from well

D. During 22 months, this well produced 9,610 barrels of oil and 7,236 barrels of water. At the end of that period, it was still producing at the rate of one barrel of oil per day with a water output to oil ratio of 20:1. The well drains 1.32 acres, which makes the oil recovery 7,280 barrels per acre. Core 11 contained 28 feet of oil-bearing sandstone. This makes the yield 260 barrels per acre-foot.

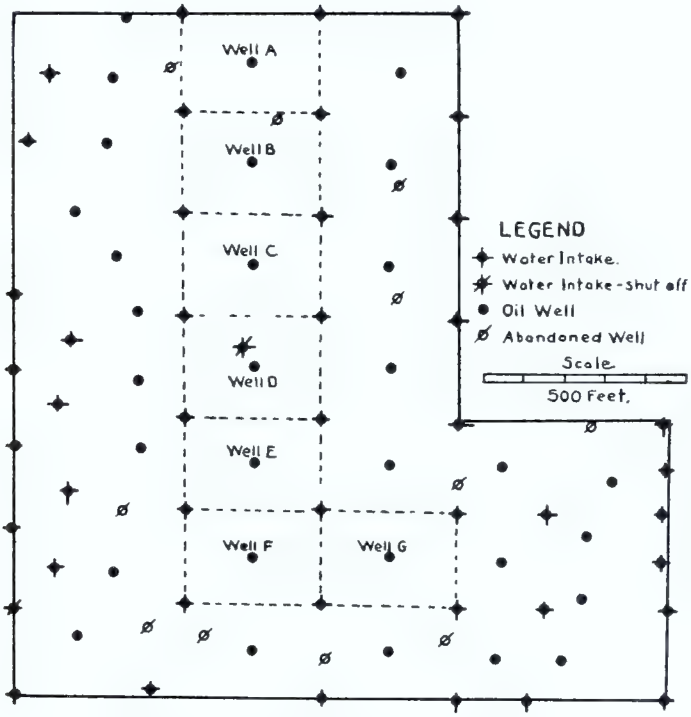


FIGURE 71. Map of Flood No. 17.

Flood No. 17

Flood No. 17 is in the Bradford pool east of Red Rock. The area of the project, whose production is now to be discussed, is shown in Figure 71. It consists of 13.2 acres. Water was first admitted to the intake wells in February 1930 and pumping of the oil wells started at the same time. At no time was production curtailed. Between February 1930 and November 1931, the pressure on the sand was 810 pounds per square inch; from November 1931 to July 1932, 850 pounds; and from July 1932 on, 960 pounds. Water is purchased from the Reclamation Supply Corporation.

From February 1930 to the end of September 1935, the seven units designated by letters in Figure 71 produced 98,777 barrels of oil, a recovery of 7,483 barrels per acre. According to the drillers' records, the sand body has an average thickness of 51 feet. It is estimated that 67 percent or 34 feet is oil-bearing sandstone. This makes the recovery 220 barrels per acre-foot. During September 1935, the average daily oil production per well was 1.6 barrels with a water output to oil ratio of 12:1. The above figures, therefore, will be increased slightly before the economic limit is attained.

The water input, oil production, water output, and recovery per acre for the seven units are given in Table 98. Water input has been calculated on the assumption that the water is distributed equally among the four quadrants around each intake well. Reference to Figure 71 shows that in this particular case even if sand conditions are uniform this is only a rough approximation as the pattern is not entirely symmetrical. During the period discussed, the water input to oil ratio was 4.90:1 and the water output to oil ratio, 1.71:1 for the seven units. The total water input for the seven units during the first year was 111,590 barrels or an average of 8,469 barrels per acre. This is equivalent to 13 inches of water. The relation of the fluid output to input for the seven units during the first nine months of 1935 is shown in Table 99.

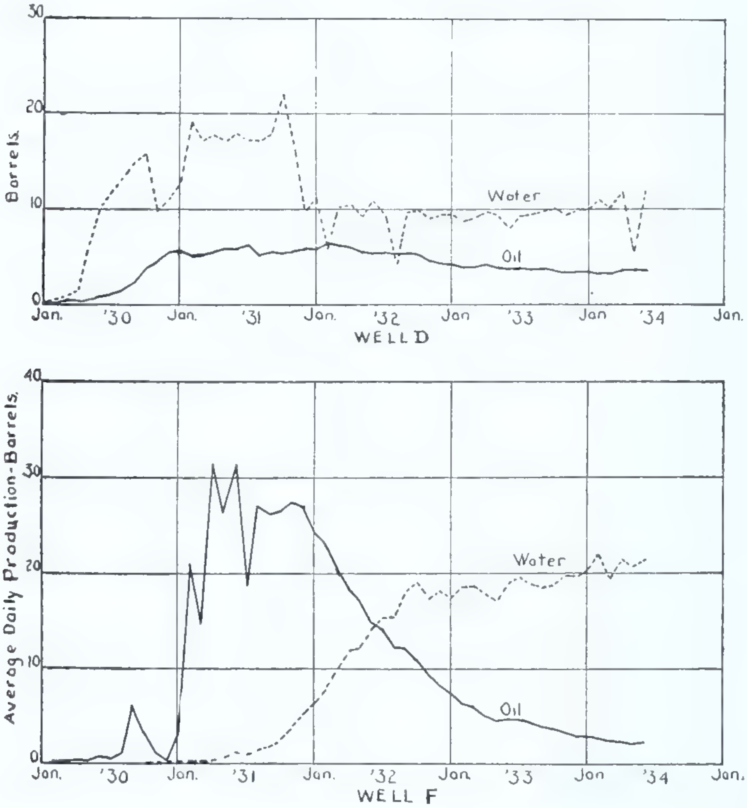


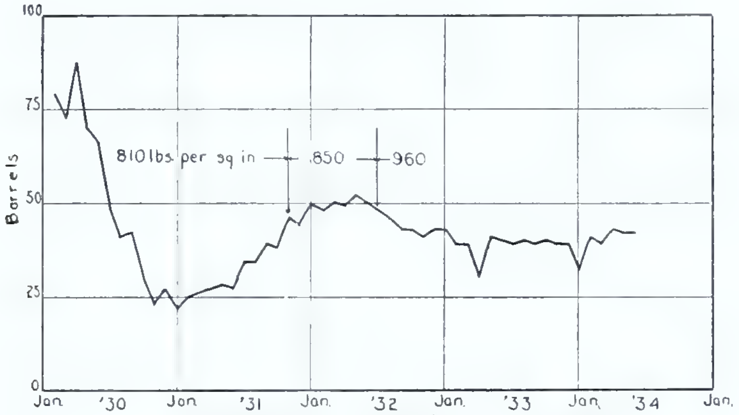
FIGURE 72. Curves showing average daily oil and water production by months of wells D and F in Flood No. 17.

Table 98. Water input, oil production, water output, and recovery per acre for seven units in Flood No. 17 to end of September, 1935, in barrels.

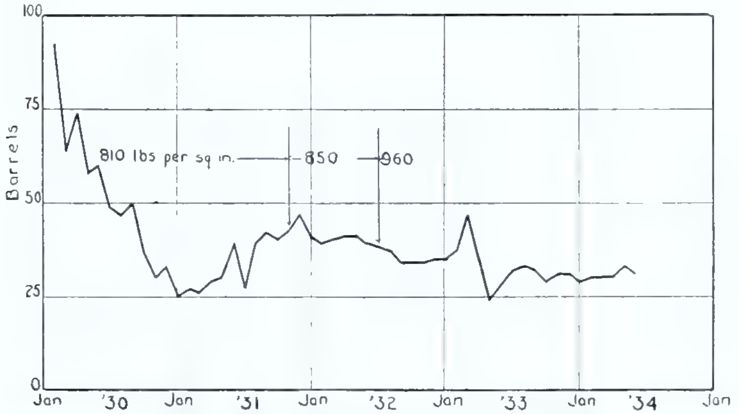
Well	Acres drained	Water input of unit	Oil production	Water output	Oil recovered per acre
A	1.82	48,356	9,316	16,087	5,119
B	2.09	56,902	11,488	20,133	5,497
C	1.95	85,473	16,873	41,984	8,653
D	1.95	86,503	6,618	17,504	3,394
E	1.79	73,577	21,795	25,614	12,176
F	1.79	74,469	17,480	25,904	9,765
G	1.81	59,118	15,207	21,453	8,402
Total	13.20	484,398	98,777	168,679	7,483

*Table 99. **Relation** of fluid output to input for six units in **Flood No. 17** during the first nine months of 1935, in barrels.*

Unit	Oil	Water output	Total fluid produced	Water input
A	395	3,382	3,777	4,754
B	653	3,848	4,501	6,309
C	581	8,113	8,694	10,031
E	592	6,143	6,735	8,898
F	370	5,685	6,055	7,933
G	431	4,445	4,876	5,449
Total	3,022	31,616	34,638	43,374



Average daily water input per well D - Unit.



Average daily water input per well F - Unit.

FIGURE 73. **Curves showing average daily water input per well for D and F units in Flood No. 17.**

The average daily and cumulative oil and water production of wells D and F and the water input for their respective units by months are given in Tables 100 and 101. The average daily production of these wells is shown graphically in Figure 72 and the average daily water input, in Figure 73. It will be noted that the oil production of well D was considerably less than that of any of the others. The reason for this apparently is an old intake well northwest of it, as shown in Figure 71. Subsurface water was let into this well on October 1, 1921 with the intention of starting a circle flood. Nine months later plans were changed and on June 24, 1922 the water was shut off. No producing wells had been drilled around it. The water must have had time, however, to reach the present site of well D, at least in the more permeable layers of sand. In order for oil to reach well D in these layers, therefore, it was necessary for it first to move the water already in the sand ahead of it. While water constitutes a good driving medium for oil, the reverse is not true. Less than half of the oil that should have been recovered from this unit was actually obtained in well D. The production records of wells C and E, however, indicate that much of the oil not recovered in well D was pushed onto these adjacent units and actually recovered in the former wells.

Table 100. Average daily and cumulative oil and water production of well D and water input for D-unit in Flood No. 17 by months, in barrels.

	Oil production		Water production		Water input	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative
1930						
Jan.	.08	2	.13	4		
Feb.	.02	3	.49	18	79	2,235
Mar.	.41	16	.76	41	72	4,473
Apr.	.25	23	1.32	81	88	7,116
May	.43	36	6.08	269	70	9,282
June	.82	61	10.20	576	66	11,247
July	1.08	95	11.67	937	49	12,790
Aug.	1.52	142	13.27	1,354	41	14,054
Sept.	2.38	213	15.09	1,807	42	15,327
Oct.	3.70	328	15.61	2,291	30	16,241
Nov.	4.48	462	9.67	2,581	23	16,945
Dec.	5.31	627	10.82	2,916	27	17,793
1931						
Jan.	5.55	799	12.60	3,297	22	18,470
Feb.	5.12	942	19.00	3,829	25	19,189
Mar.	5.21	1,104	17.16	4,361	26	20,003
Apr.	5.47	1,268	17.74	4,893	27	20,828
May	5.74	1,446	17.16	5,425	28	21,677
June	5.81	1,620	17.74	5,957	27	22,511
July	6.20	1,812	17.16	6,489	34	23,563
Aug.	5.06	1,969	17.16	7,022	34	24,645
Sept.	5.33	2,129	17.74	7,554	39	25,705
Oct.	5.28	2,293	22.05	8,237	38	26,896
Nov.	5.59	2,460	16.27	8,725	46	28,272
Dec.	5.66	2,636	9.44	9,018	44	29,540
1932						
Jan.	5.66	2,811	11.11	9,362	50	31,067
Feb.	6.38	2,996	5.63	9,525	48	32,487
Mar.	6.03	3,183	10.17	9,841	50	34,033
Apr.	5.71	3,354	10.36	10,152	49	35,522
May	5.53	3,526	9.08	10,433	52	37,137
June	5.41	3,688	10.92	10,761	50	38,644
July	5.45	3,857	9.26	11,048	48	40,140
Aug.	5.25	4,020	3.90	11,169	46	41,563
Sept.	5.26	4,177	9.61	11,457	43	42,855
Oct.	5.19	4,339	9.81	11,761	43	44,184
Nov.	4.59	4,476	9.07	12,033	41	45,411
Dec.	4.31	4,610	9.43	12,325	43	46,785
1933						
Jan.	4.27	4,742	9.26	12,613	43	48,124
Feb.	3.97	4,853	8.71	12,856	39	49,220
Mar.	3.98	4,977	9.08	13,138	39	50,434
Apr.	4.07	5,099	9.65	13,427	30	51,099
May	3.96	5,221	9.26	13,714	41	52,611
June	3.76	5,334	7.97	13,954	40	53,807
July	3.77	5,451	9.26	14,241	39	55,017
Aug.	3.74	5,567	9.55	14,536	40	56,245
Sept.	3.74	5,679	9.64	14,825	39	57,411
Oct.	3.54	5,790	9.99	15,135	40	58,661
Nov.	3.42	5,892	9.46	15,418	39	59,832
Dec.	3.40	5,998	9.81	15,722	39	60,805
1934						
Jan.	3.32	6,101	9.82	16,027	32	61,792
Feb.	3.34	6,194	10.93	16,333	41	62,773
Mar.	3.30	6,296	10.01	16,643	39	63,979
Apr.	3.45	6,400	11.85	16,999	43	65,265
May	3.61	6,512	5.37	17,165	42	66,568
June	3.54	6,618	11.31	17,504	42	67,815

Table 101. Average daily and cumulative oil and water production of well F and water input for F-unit in Flood No. 17 by months, in barrels.

	Oil production		Water production		Water input	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative
1930						
Jan.						
Feb.					69	1,399
Mar.	.17	5			48	2,890
Apr.	.36	16			74	5,127
May	.27	25			58	6,956
June	.51	40			60	8,769
July	.40	52	.01		49	10,293
Aug.	.91	81	.04	1	47	11,764
Sept.	6.04	262	.02	2	50	13,285
Oct.	2.81	349	.01	2	37	14,454
Nov.	1.02	380	.01	3	30	15,350
Dec.	.25	387	.01	3	33	16,368
1931						
Jan.	3.24	488	.04	4	25	17,138
Feb.	22.18	1,109	.07	6	27	17,905
Mar.	14.52	1,559	.04	8	26	18,725
Apr.	31.44	2,502	.23	14	29	19,588
May	26.19	3,314	.67	35	30	20,531
June	31.37	4,256	1.07	67	39	21,434
July	18.59	4,832	.91	95	27	22,267
Aug.	27.18	5,674	1.49	142	39	23,489
Sept.	26.23	6,461	1.76	194	42	24,743
Oct.	26.57	7,284	2.46	271	40	25,991
Nov.	27.39	8,106	4.00	391	43	27,286
Dec.	27.09	8,946	5.08	548	47	28,634
1932						
Jan.	24.32	9,700	6.37	745	41	29,895
Feb.	23.02	10,367	7.92	975	39	31,016
Mar.	20.48	11,002	9.97	1,284	40	32,229
Apr.	18.40	11,524	11.83	1,639	41	33,455
May	17.04	12,052	12.27	2,020	41	34,731
June	15.05	12,504	13.91	2,437	39	35,893
July	14.20	12,944	15.37	2,913	38	37,070
Aug.	12.15	13,321	15.38	3,390	37	38,211
Sept.	12.19	13,686	18.14	3,934	34	39,232
Oct.	11.16	14,033	19.09	4,526	34	40,289
Nov.	9.45	14,317	17.23	5,043	34	41,340
Dec.	8.19	14,570	18.15	5,606	35	42,442
1933						
Jan.	7.48	14,802	17.41	6,145	35	43,514
Feb.	6.27	14,978	18.71	6,669	37	44,540
Mar.	5.94	15,162	18.70	7,249	47	46,016
Apr.	5.09	15,315	17.96	7,788	35	47,081
May	4.50	15,454	17.21	8,321	24	47,813
June	4.74	15,596	19.03	8,892	28	48,647
July	4.68	15,741	19.62	9,500	32	49,689
Aug.	4.37	15,876	18.89	10,086	33	50,649
Sept.	3.98	15,995	18.51	10,641	32	51,607
Oct.	3.81	16,114	18.71	11,221	29	52,515
Nov.	3.37	16,215	19.79	11,815	31	53,457
Dec.	3.01	16,309	19.76	12,428	31	54,425
1934						
Jan.	2.89	16,398	20.38	13,059	29	55,203
Feb.	2.73	16,474	22.04	13,677	30	56,052
Mar.	2.42	16,549	19.44	14,279	30	56,993
Apr.	2.35	16,620	21.47	14,923	30	57,967
May	2.08	16,684	20.74	15,573	33	58,998
June	2.19	16,749	21.29	16,212	31	59,868
July	2.10	16,815	21.67	16,884	32	60,867
Aug.	2.11	16,881	21.86	17,561	35	61,937
Sept.	2.16	16,945	22.40	18.233	34	62,960
Oct.	1.85	17,003	21.85	18,911	35	64,029
Nov.	1.80	17,057	22.57	19,588	32	64,979
Dec.	1.72	17,110	20.36	20,219	32	65,970
1935						
Jan.	1.52	17,157	20.17	20,844	33	66,984
Feb.	1.57	17,201	21.68	21,451	32	67,875
Mar.	1.40	17,245	21.84	22,128	39	69,096
Apr.	1.36	17,285	18.23	22,675	29	69,979
May	1.25	17,324	20.56	23,313	29	70,881
June	1.33	17,364	20.92	23,940	31	71,816
July	1.28	17,404	22.40	24,635	32	72,802
Aug.	1.32	17,445	21.29	25,295	31	73,779
Sept.	1.57	17,480	20.36	25,904	32	74,742

Flood No. 18

Flood No. 18 is an extensive five-spot development in the Bradford pool near Rixford. As shown in Figure 74, the property was developed in two tracts. Production started on the southern tract on November 1, 1928 and on the northern tract one year later. The distance between water intake and oil wells is 200 feet. Water for flooding is obtained from wells sunk in the alluvium along the South Branch of Knapp Creek below Rixford. The water is not filtered. During 1929 the pump pressure maintained at the plant was such that an average pressure of 720 pounds per square inch was obtained at the face of the sand in the intake wells; during 1930 this was 770 pounds; during 1931, 800 pounds; during 1932, 810 pounds; during 1933, 920 pounds, and during 1934, 970 pounds. Production on both tracts was curtailed during parts of 1930, 1931 and 1932, the southern tract being curtailed longer than the northern. As a result, the recovery per acre-foot to March 22, 1935 was

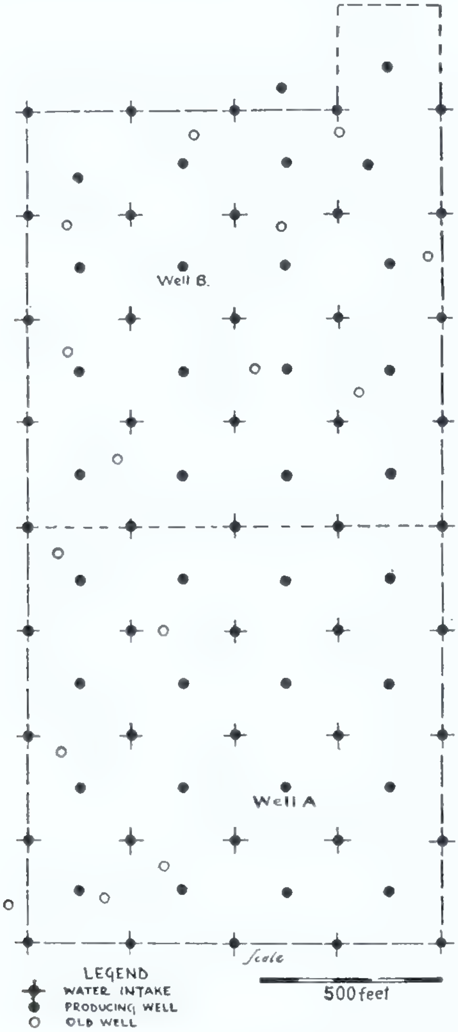


FIGURE 74. Map of Flood No. 18.

about the same for both tracts, although production on one started a year in advance of the other. Gauging of the water output was stopped at the end of 1931.

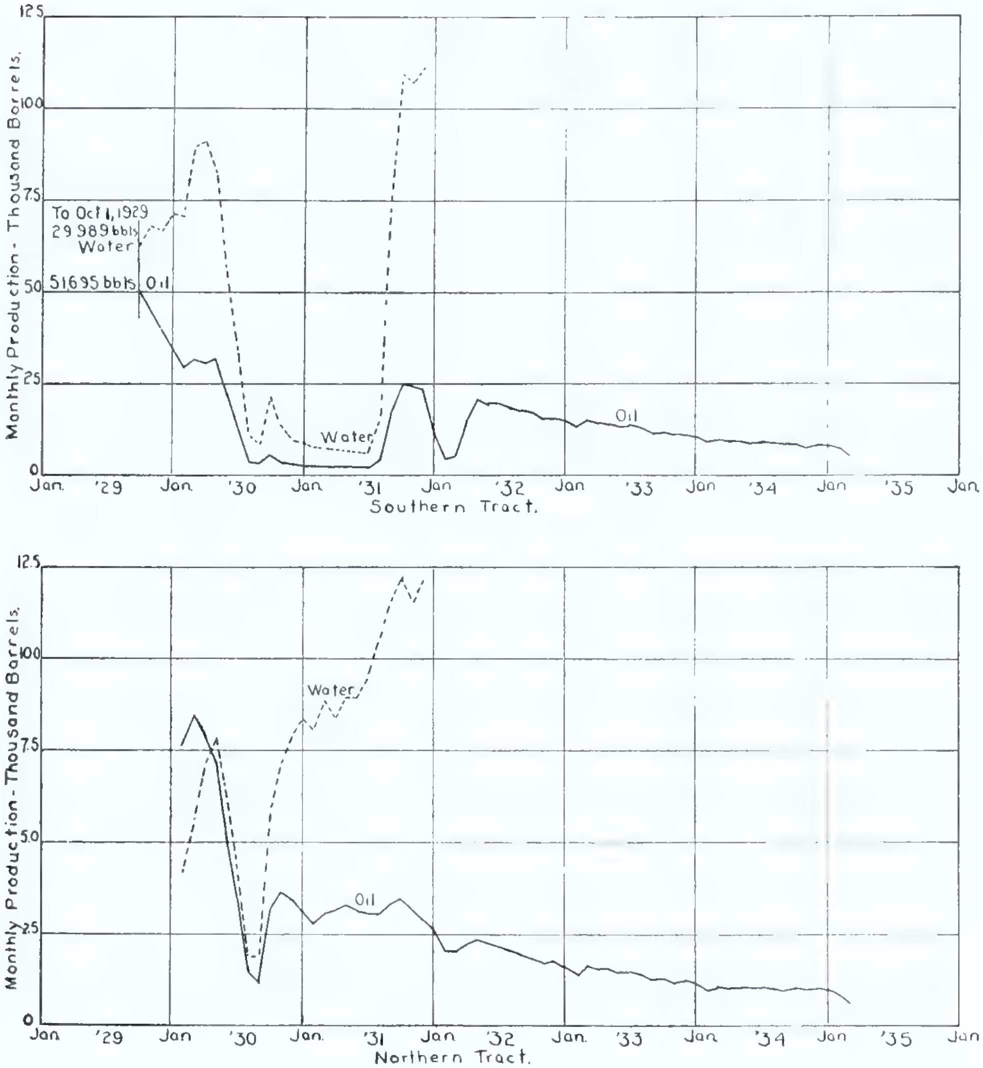


FIGURE 75. **Curves showing total monthly oil and water production of southern and northern tracts in Flood No. 18.**

At the end of March 22, 1935, the southern tract of 28.8 acres had yielded 144,394 barrels of oil, a recovery of 5,014 barrels per acre. According to the drillers' records, the sand body on this tract has an average thickness of 41 feet. It is estimated that 64 percent or 26 feet of this is oil-bearing sandstone, which makes the yield 193 barrels per acre-foot. At the end of March 1935, the 16 producing wells still averaged 1.58 barrels of oil per well per day so that the above figures will be increased somewhat before the economic limit of production is reached. At the end of 1931, the total water output to oil ratio was 1.56:1. About 67 percent of the total amount of oil recovered to the end of March 22, 1935 had been obtained at the end of 1931.

At the end of March 22, 1935, the northern tract of 30.6 acres had yielded 161,140 barrels of oil, a recovery of 5,266 barrels per acre. According to the drillers' records, the sand body on this tract has an average thickness of 43 feet. It is estimated that 28 feet of this is oil-bearing sandstone, which makes the yield 188 barrels per acre-foot. At the end of March 1935, the 17 producing wells still averaged 1.47 barrels of oil per well per day. At the end of 1931, the total water output to oil ratio was 1.78:1. About 62 percent of the total amount of oil recovered to the end of March 22, 1935 had been obtained at the end of 1931.

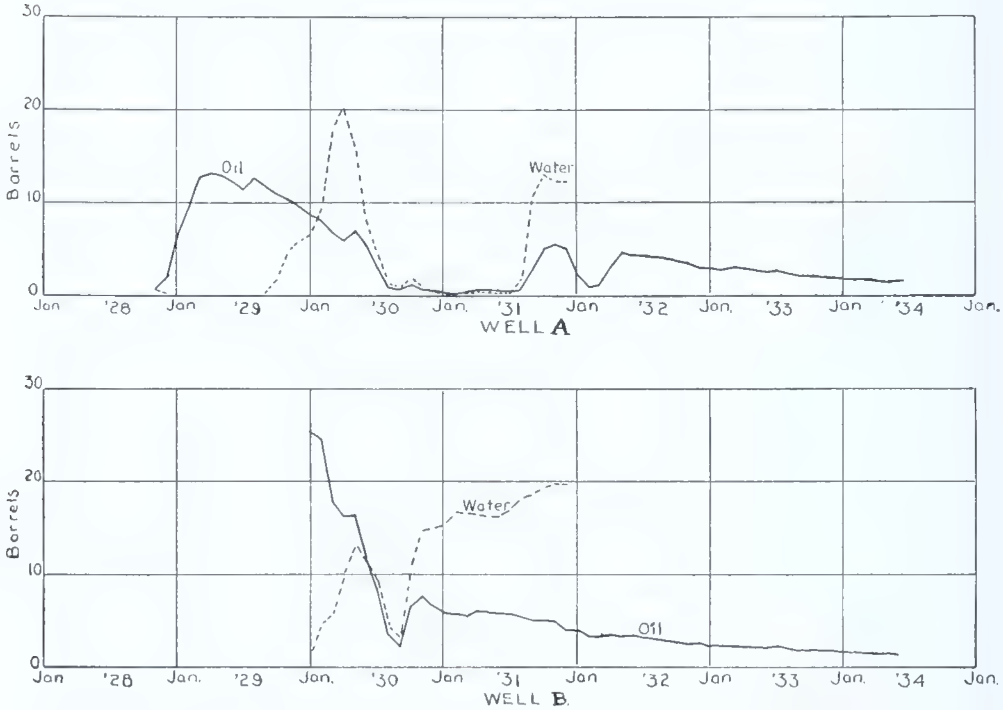


FIGURE 76. **Curves showing average daily oil and water production by months of wells A and B in Flood No. 18.**

The total monthly and cumulative oil and water production of the southern and northern tracts in Flood No. 18 is given in Table 102. The monthly production is shown graphically in Figure 75. The average daily and cumulative oil and water production by months of two typical wells is given in Table 103. Well A is in the southern tract and B in the northern. Their daily production is shown graphically in Figure 76. It will be observed that the oil wells in the southern tract were completed at about the same time the water was admitted to the intake wells, while in the northern tract, the drilling of the oil wells was delayed somewhat.

Table 102. Total monthly and cumulative oil and water production of southern and northern tracts in Flood No. 18, in barrels.

	Southern tract			
	Oil		Water	
Date	Monthly	Cumulative	Monthly	Cumulative
1929	(first year)	51,695	(first year)	29,989
Oct.	5,027	56,722	6,259	36,248
Nov.	4,485	61,208	6,815	43,063
Dec.	3,906	65,114	6,663	49,727
1930				
Jan.	3,468	68,582	7,104	56,831
Feb.	2,954	71,536	7,036	63,867
Mar.	3,117	74,653	8,958	72,825
Apr.	3,065	77,718	9,107	81,932
May	3,196	80,915	8,212	90,144
June	2,253	83,168	5,583	95,727
July	1,273	84,441	3,391	99,119
Aug.	395	84,836	1,063	100,182
Sept.	318	85,154	857	101,039
Oct.	557	85,711	2,161	103,201
Nov.	399	86,110	1,366	104,567
Dec.	329	86,439	938	105,504
1931				
Jan.	285	86,723	853	106,357
Feb.	260	86,983	731	107,088
Mar.	258	87,241	743	107,831
Apr.	256	87,496	711	108,542
May	253	87,750	661	109,203
June	229	87,978	610	109,813
July	234	88,212	619	110,432
Aug.	413	88,626	1,513	111,945
Sept.	1,628	90,253	7,112	119,057
Oct.	2,502	92,755	10,901	129,958
Nov.	2,423	95,178	10,790	140,748
Dec.	2,348	97,526	11,149	151,898
1932				
Jan.	1,101	98,627		
Feb.	457	99,084		
Mar.	503	99,587		
Apr.	1,434	101,021		
May	2,090	103,112		
June	1,985	105,096		
July	1,977	107,073		
Aug.	1,883	108,956		
Sept.	1,747	110,704		
Oct.	1,717	112,421		
Nov.	1,579	114,000		
Dec.	1,567	115,567		
1933				
Jan.	1,529	117,096		
Feb.	1,325	118,421		
Mar.	1,521	119,942		
Apr.	1,443	121,386		
May	1,429	122,814		
June	1,340	124,155		
July	1,389	125,544		
Aug.	1,319	126,863		
Sept.	1,152	128,015		
Oct.	1,174	129,190		
Nov.	1,140	130,330		
Dec.	1,125	131,455		
1934				
Jan.	1,060	132,515		
Feb.	916	133,433		
Mar.	975	134,408		
Apr.	913	135,321		
May	919	136,241		
June	880	137,123		
July	901	138,025		
Aug.	885	138,909		
Sept.	862	139,771		
Oct.	875	140,646		
Nov.	790	141,436		
Dec.	832	142,268		
1935				
Jan.	831	143,099		
Feb.	738	143,837		
Mar.	557	144,394		

	Northern tract			
	Oil		Water	
Date	Monthly	Cumulative	Monthly	Cumulative
(Prior to Feb. 1930)		12,907		4,980
Feb.	7,659	20,567	4,165	9,145
Mar.	8,485	29,052	5,579	14,734
Apr.	7,932	36,984	7,145	21,869
May	7,161	44,145	7,862	29,731
June	5,234	49,380	6,456	36,187
July	3,438	52,817	4,428	40,615
Aug.	1,428	54,245	1,862	42,477
Sept.	1,190	55,435	1,867	44,344
Oct.	3,205	58,641	5,864	50,208
Nov.	3,640	62,281	7,113	57,321
Dec.	3,463	65,745	7,906	65,227
1931				
Jan.	3,142	68,887	8,343	73,569
Feb.	2,803	71,690	8,098	81,667
Mar.	3,050	74,740	8,858	90,525
Apr.	3,195	77,935	8,351	98,876
May	3,309	81,244	8,910	107,786
June	3,157	84,401	8,938	116,724
July	3,099	87,501	9,545	126,269
Aug.	3,058	90,559	10,543	136,812
Sept.	3,309	93,868	11,530	148,342
Oct.	3,466	97,334	12,162	160,504
Nov.	3,207	100,541	11,699	172,203
Dec.	2,902	103,443	12,089	184,292
1932				
Jan.	2,676	106,119		
Feb.	2,066	108,185		
Mar.	2,023	110,208		
Apr.	2,253	112,462		
May	2,371	114,833		
June	2,216	117,048		
July	2,189	119,237		
Aug.	2,092	121,328		
Sept.	1,915	123,243		
Oct.	1,862	125,106		
Nov.	1,743	126,849		
Dec.	1,774	128,622		
1933				
Jan.	1,650	130,273		
Feb.	1,423	131,696		
Mar.	1,647	133,343		
Apr.	1,565	134,908		
May	1,587	136,495		
June	1,494	137,989		
July	1,507	139,496		
Aug.	1,413	140,909		
Sept.	1,280	142,188		
Oct.	1,301	143,490		
Nov.	1,208	144,698		
Dec.	1,233	145,931		
1934				
Jan.	1,169	147,100		
Feb.	999	148,099		
Mar.	1,097	149,196		
Apr.	1,053	150,249		
May	1,054	151,303		
June	1,013	152,317		
July	1,035	153,352		
Aug.	1,019	154,471		
Sept.	981	155,452		
Oct.	1,039	156,491		
Nov.	1,003	157,494		
Dec.	1,033	158,527		
1935				
Jan.	1,019	159,546		
Feb.	900	160,446		
Mar.	694	161,140		

Table 103. Average daily and cumulative oil and water production of wells A and B in Flood No. 18, by months, in barrels.

Well A

Date	Oil Daily	Oil Cumulative	Water Daily	Water Cumulative
1928				
Nov.	.57	17	.56	2
Dec.	1.95	78	.18	7
1929				
Jan.	6.28	272		13
Feb.	9.14	528		
Mar.	12.71	922		
Apr.	13.00	1,312		
May	12.94	1,713		
June	12.28	2,082		
July	11.41	2,436	.04	14
Aug.	12.44	2,821		
Sept.	11.62	3,169	.27	22
Oct.	10.92	3,508	1.62	72
Nov.	10.40	3,820	4.81	217
Dec.	9.54	4,115	5.88	399
1930				
Jan.	8.50	4,379	6.46	599
Feb.	8.03	4,604	9.61	868
Mar.	6.67	4,811	17.80	1,420
Apr.	5.95	4,989	20.10	2,023
May	6.95	5,305	15.90	2,516
June	5.50	5,370	8.11	2,759
July	3.03	5,463	4.52	2,899
Aug.	.85	5,490	.95	2,929
Sept.	.65	5,509	.68	2,949
Oct.	1.07	5,542	1.85	3,007
Nov.	.54	5,559	.70	3,028
Dec.	.50	5,574	.40	3,040
1931				
Jan.	.24	5,582	.21	3,047
Feb.	.22	5,588	.17	3,051
Mar.	.40	5,600	.19	3,057
Apr.	.53	5,615	.36	3,058
May	.48	5,631	.34	3,078
June	.45	5,644	.29	3,087
July	.42	5,657	.30	3,097
Aug.	.59	5,676	1.71	3,149
Sept.	2.89	5,762	10.58	3,467
Oct.	5.17	5,923	13.06	3,872
Nov.	5.36	6,089	12.21	4,238
Dec.	5.07	6,246	12.21	4,617
1932				
Jan.	2.14	6,312		
Feb.	.86	6,337		
Mar.	1.04	6,369		
Apr.	3.11	6,463		
May	4.45	6,601		
June	4.35	6,731		
July	4.29	6,864		
Aug.	4.12	6,992		
Sept.	3.88	7,108		
Oct.	3.72	7,223		
Nov.	3.58	7,331		
Dec.	3.11	7,427		
1933				
Jan.	2.94	7,519		
Feb.	2.81	7,597		
Mar.	2.92	7,688		
Apr.	2.83	7,772		
May	2.65	7,855		
June	2.57	7,932		
July	2.62	8,013		
Aug.	2.36	8,086		
Sept.	2.05	8.148		
Oct.	2.01	8,210		
Nov.	1.95	8,268		
Dec.	1.92	8,328		
1934				
Jan.	1.78	8,383		
Feb.	1.74	8,432		
Mar.	1.64	8,483		
Apr.	1.55	8,529		
May	1.51	8,657		
June	1.62	8,600		

Well B

Date	Oil Daily	Oil Cumulative	Water Daily	Water Cumulative
1930				
Jan.	25.26	783	1.72	53
Feb.	24.50	1,469	4.77	187
Mar.	17.77	2,020	5.72	365
Apr.	16.27	2,514	9.88	661
May	16.39	3,022	13.01	1,064
June	11.47	3,378	11.18	1,399
July	8.34	3,637	8.80	1,672
Aug.	3.48	3,744	4.31	1,805
Sept.	2.18	3,810	3.09	1,898
Oct.	6.51	4,012	10.95	2,237
Nov.	7.58	4,239	14.70	2,678
Dec.	6.67	4,446	15.12	3,147
1931				
Jan.	5.94	4,630	15.30	3,621
Feb.	5.77	4,792	16.65	4,087
Mar.	5.53	4,963	16.57	4,601
Apr.	5.99	5,143	16.32	5,091
May	5.93	5,327	16.05	5,588
June	5.87	5,503	16.21	6,075
July	5.63	5,677	16.94	6,600
Aug.	5.40	5,844	18.25	7,165
Sept.	5.18	6,000	18.60	7,524
Oct.	5.15	6,159	19.33	8,124
Nov.	4.87	6,305	19.71	8,715
Dec.	4.12	6,433	19.71	9,326
1932				
Jan.	4.00	6,557		
Feb.	3.47	6,658		
Mar.	3.30	6,760		
Apr.	3.49	6,865		
May	3.41	6,971		
June	3.45	7,074		
July	3.21	7,174		
Aug.	3.04	7,268		
Sept.	2.82	7,353		
Oct.	2.69	7,436		
Nov.	2.58	7,513		
Dec.	2.61	7,594		
1933				
Jan.	2.38	7,668		
Feb.	2.33	7,734		
Mar.	2.37	7,807		
Apr.	2.33	7,877		
May	2.31	7,949		
June	2.25	8,016		
July	2.19	8,084		
Aug.	2.03	8,147		
Sept.	1.94	8,205		
Oct.	1.87	8,264		
Nov.	1.82	8,318		
Dec.	1.85	8,376		
1934				
Jan.	1.76	8,430		
Feb.	1.78	8,480		
Mar.	1.69	8,532		
Apr.	1.55	8,579		
May	1.56	8,627		
June	1.53	8,650		

Flood No. 19

Flood No. 19 is part of a flooding operation on a property in the Bradford pool north of Duke Center. The position of the four units of a five-spot development, whose production is discussed, with respect to a circle flood in existence on the property when the more intensive method of flooding was adopted, is shown in Figure 77. In the five-spot development, the distance between the water-input and oil wells is 154 feet. Prior to November 1929, only subsurface water had been admitted to the input wells. After that date, water obtained from a well sunk in the alluvium of Oil Valley nearby was substituted. The water is not filtered. Just enough pump pressure has been maintained at the water plant to raise the water to the top of the highest well on the property. This is equivalent to about 700 pounds per square inch at the face of the sand in the intake wells. Core No. 7, already described,

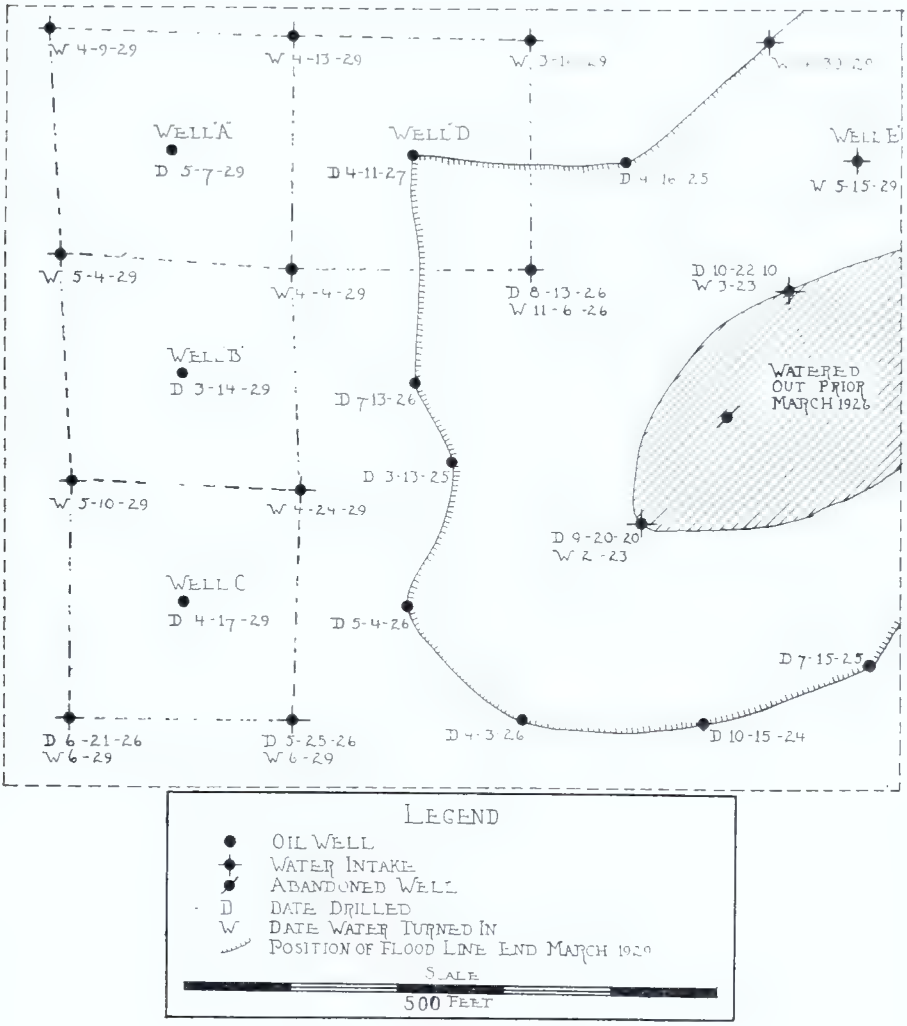


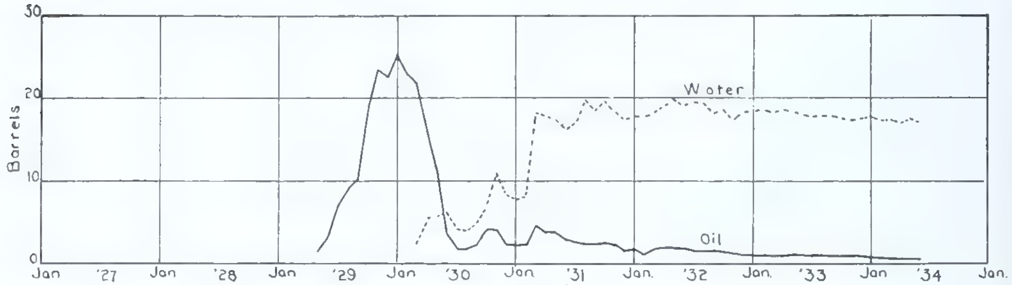
FIGURE 77. Map of Flood No. 19.

came from well E, whose location is shown in Figure 77. Production was curtailed at intervals between May 1930 and March 1932.

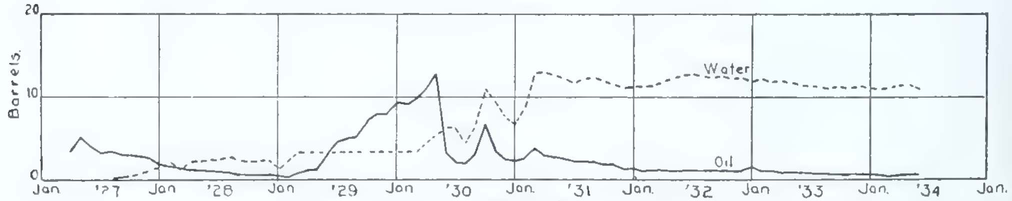
At the end of June 1934, the four units shown in Figure 77 had yielded 31,163 barrels of oil, an average recovery of 7,131 barrels per acre. According to the drillers' records, the sand body has an average thickness of 50 feet. Core 7 showed that 76 percent or 38 feet is oil-bearing sandstone, making the recovery 188 barrels per acre-foot. To the end of June 1934, the water output to oil ratio was 2.85:1. At the end of this period, the average daily oil production per well was down to .6 barrels with a water output to oil ratio of 25:1. The above figures, therefore, will not be changed very much by the time the economic limit is reached. A summary of the performance of the four wells is given in Table 104.

Table 104. Summary of performance of four wells in Flood No. 19.

Well	A	B	C	D
Total thickness of sand body (ft.)	48	52	51	48
Estimated thickness of oil-bearing sandstone (ft.)	36	40	39	36
Area of unit (acres)	1.10	1.07	1.08	1.12
Oil production to end of June 1934 (bbls.)	8,510	7,439	8,739	6,475
Water output to end of June 1934 (bbls.)	24,236	21,817	23,826	18,818
Water output to oil ratio	2.85	2.93	2.73	2.91
Oil removed per acre (bbls.)	7,736	6,952	8,091	5,781
Oil removed per acre-foot (bbls.)	215	174	207	161



WELL A.



WELL D.

FIGURE 78. **Curves showing average daily oil and water production by months of wells A and D in Flood No. 19.**

The average daily and the cumulative oil and water production by months of wells A and D are given in Table 105 and their average daily production is shown graphically in Figure 78. As shown in Figure 77, well D is at what was the edge of an encroaching circle flood when the five-spot development started. At the end of March 1929, the well had already produced 1,263 barrels of oil or 20 percent of its total output. Its production had dropped from a peak of 5.16 barrels per day to 0.63 barrels with a water output to oil ratio of 5:1 at the time it became the center of a five-spot unit.

Table 105. Average daily and cumulative oil and water production of wells A and D in Flood No. 19 by months, in barrels.

Well A

Date	Oil		Water	
	Daily	Cumulative	Daily	Cumulative
1927				
Apr.				
May				
June				
July				
Aug.				
Sept.				
Oct.				
Nov.				
Dec.				
1928				
Jan.				
Feb.				
Mar.				
Apr.				
May				
June				
July				
Aug.				
Sept.				
Oct.				
Nov.				
Dec.				
1929				
Jan.				
Feb.				
Mar.				
Apr.				
May	1.39	43		
June	3.18	139		
July	6.85	351		
Aug.	8.56	616		
Sept.	10.25	924		
Oct.	18.56	1,500		
Nov.	23.32	2,199		
Dec.	22.41	2,894		
1930				
Jan.	25.33	3,679		
Feb.	22.83	4,318		
Mar.	21.82	4,995	2.48	77
Apr.	16.15	5,479	5.40	239
May	11.42	5,833	5.62	413
June	3.62	5,942	6.21	599
July	1.77	5,997	4.06	725
Aug.	1.81	6,053	3.89	846
Sept.	2.24	6,120	4.64	985
Oct.	4.06	6,246	6.81	1,087
Nov.	4.03	6,367	10.91	1,414
Dec.	2.33	6,439	8.35	1.673
1931				
Jan.	2.16	6,506	7.66	1,911
Feb.	2.19	6,568	8.01	2,135
Mar.	4.67	6,713	18.22	2,700
Apr.	3.78	6,826	17.76	3,233
May	3.75	6,942	17.45	3,773
June	2.98	7,031	16.27	4,262
July	2.71	7,115	17.17	4,794
Aug.	2.39	7,190	19.88	5,411
Sept.	2.42	7,262	18.39	5,962
Oct.	2.45	7,338	19.75	6,575
Nov.	2.36	7,407	18.73	7,137
Dec.	1.57	7,456	17.34	7,674
1932				
Jan.	1.63	7,506	17.78	8,225
Feb.	1.07	7,538	17.78	8,723
Mar.	1.81	7,594	18.22	9,288
Apr.	1.97	7,653	19.00	9,858
May	1.91	7,712	19.79	10,471
June	1.72	7,664	19.21	11,067
July	1.53	7,811	19.55	11,673
Aug.	1.53	7,859	19.42	12,275
Sept.	1.51	7,904	18.34	12,825
Oct.	1.29	7,944	18.63	13,403
Nov.	1.19	7,980	17.51	13,928
Dec.	1.18	8,016	18.39	14,498
1933				
Jan.	1.12	8,051	18.39	15,068
Feb.	1.02	8,080	18.58	15,589
Mar.	.93	8,109	18.38	16,158
Apr.	.99	8,138	18.56	16,715
May	1.06	8,171	18.39	17,285
June	1.06	8,203	18.00	17,825
July	1.06	8,236	17.85	18,279
Aug.	1.05	8,268	17.98	18,936
Sept.	.96	8,297	17.79	19,470
Oct.	.94	8,326	17.50	20,012
Nov.	.86	8,352	17.32	20,532
Dec.	.86	8,379	17.50	21,074
1934				
Jan.	.82	8,404	17.87	21,628
Feb.	.77	8,426	17.42	22,133
Mar.	.74	8,449	17.31	22,670
Apr.	.68	8,469	17.03	23,181
May	.67	8,490	17.49	23,723
June	.67	8,510	17.10	24,236

Well D

Date	Oil		Water	
	Daily	Cumulative	Daily	Cumulative
1927				
Apr.	3.45	66		
May	5.16	225		
June	3.87	341		
July	3.16	439		
Aug.	3.36	544	.16	5
Sept.	2.84	629	.28	13
Oct.	2.93	720	.37	25
Nov.	2.82	804	.76	49
Dec.	2.43	880	1.17	85
1928				
Jan.	1.94	940	1.47	130
Feb.	1.49	983	1.92	186
Mar.	1.27	1,022	1.99	248
Apr.	1.08	1,055	2.06	310
May	.99	1,085	2.16	377
June	1.02	1,116	2.26	445
July	.85	1,143	2.21	514
Aug.	.79	1,167	2.71	598
Sept.	.63	1,186	2.23	665
Oct.	.53	1,203	2.12	730
Nov.	.52	1,218	2.13	794
Dec.	.48	1,233	2.17	862
1929				
Jan.	.26	1,242	1.15	897
Feb.	.06	1,243	2.11	957
Mar.	.63	1,263	3.20	1,050
Apr.	1.15	1,297	3.20	1,144
May	1.17	1,352	3.20	1,238
June	2.85	1,438	3.20	1,332
July	4.43	1,575	3.20	1,426
Aug.	4.98	1,730	3.20	1,520

Well D (Continued)

	Oil		Water	
Date	Daily	Cumulative	Daily	Cumulative
Sept.	5.07	1,882	3.20	1,614
Oct.	6.92	2,096	3.20	1,708
Nov.	7.91	2,334	3.20	1,802
Dec.	7.90	2,579	3.20	1,895
1930				
Jan.	9.26	2,866	3.20	1,989
Feb.	9.13	3,122	3.20	2,083
Mar.	9.73	3,423	3.20	2,177
Apr.	11.16	3,758	4.29	2,306
May	13.01	4,162	9.38	2,597
June	3.20	4,258	6.03	2,777
July	1.99	4,319	6.05	2,965
Aug.	1.96	4,380	4.31	3,099
Sept.	3.16	4,475	6.48	3,293
Oct.	6.62	4,680	10.94	3,632
Nov.	3.39	4,782	9.23	3,818
Dec.	2.41	4,856	7.51	4,151
1931				
Jan.	2.29	4,928	6.56	4,354
Feb.	2.65	5,002	8.76	4,500
Mar.	3.63	5,114	12.83	4,897
Apr.	2.84	5,200	12.96	5,286
May	2.74	5,285	12.64	5,678
June	2.48	5,359	12.25	6,045
July	2.25	5,429	11.49	6,402
Aug.	2.20	5,497	12.20	6,780
Sept.	2.06	5,559	12.31	7,149
Oct.	1.83	5,616	11.93	7,519
Nov.	1.71	5,667	11.55	7,865
Dec.	1.19	5,704	11.17	8,212
Jan.	1.26	5,743	11.22	8,560
Feb.	.92	5,770	11.22	8,874
Mar.	1.03	5,802	11.26	9,223
Apr.	1.07	5,834	11.79	9,577
May	1.06	5,867	12.31	9,958
June	1.06	5,898	12.59	10,336
July	1.06	5,931	12.76	10,731
Aug.	1.06	5,964	12.49	11,118
Sept.	1.06	5,996	12.22	11,485
Oct.	1.06	6,029	12.44	11,871
Nov.	1.06	6,060	12.06	12,232
Dec.	1.06	6,093	12.19	12,610
1933				
Jan.	1.54	6,126	11.74	12,974
Feb.	.97	6,153	12.09	13,313
Mar.	.96	6,183	11.75	13,677
Apr.	.82	6,207	11.93	14,035
May	.87	6,234	11.63	14,395
June	.82	6,259	11.43	14,738
July	.77	6,283	11.29	15,088
Aug.	.75	6,306	11.14	15,434
Sept.	.71	6,327	11.00	15,764
Oct.	.65	6,347	11.19	16,111
Nov.	.60	6,365	11.09	16,454
Dec.	.58	6,383	11.29	16,804
1934				
Jan.	.58	6,401	11.04	17,147
Feb.	.55	6,417	10.91	17,452
Mar.	.31	6,426	11.07	17,796
Apr.	.46	6,440	11.23	18,132
May	.58	6,458	11.49	18,488
June	.58	6,475	10.98	18,818
1932				

In order for oil to reach the well, therefore, from the remaining three-quarters of the unit, it had to traverse at least a narrow zone of already watered-out sand surrounding the well. It will be noted that the oil recovery from well D was considerably below that of the other three units discussed. This well illustrates a condition similar to that of well D in Flood No. 17. Oil cannot be driven efficiently toward wells drilled into sand already flooded.

Flood No. 20

Flood No. 20 is a five-spot development on a tract of 63.8 acres in the Bradford pool near South Bradford. The distance between water intake wells is 215 feet and between water intake and oil wells, 152 feet, except where the pattern had to be adjusted to the boundaries. Water for flooding is obtained from wells sunk in the alluvium of the East Branch of Tunungwant Valley. It is not filtered. To the end of September 1931, the pump pressure at the water plant was maintained at a level to give a pressure of 715 pounds per square inch on the face of the sand in the intake wells. Between October 1931 and April 1932, it was 760 pounds; between May 1932 and May 1933, 795 pounds; and since June 1933, 835 pounds. Production started in October 1929 but was drastically curtailed during 1930 and 1931 on account of proration. This was accomplished by pumping daily only the water from the producing wells and allowing the oil to head up in the wells. The back pressure thus developed was very effective in cutting down the production of the oil wells and also in reducing the amount of water that the input wells would take.

Between October 1929 and July 1935, the tract of 63.8 acres yielded 309,444 barrels of oil, a recovery of 4,850 barrels per acre. According to the drillers' records, the sand body has an average thickness of 59 feet. It is estimated that 72 percent or 42 feet of this is oil-bearing sandstone, making the yield 115 barrels per acre-foot. During the above period, the total input was 2,267,081 barrels, giving a water input to oil ratio of 7.33:1. At the end of July 1935, the oil wells were still averaging 1.54 barrels of oil per well per day. The above figures will, therefore, be increased somewhat before the economic limit is reached. The water input during the first year averaged 7,770 barrels per acre, which is equivalent to 12 inches.

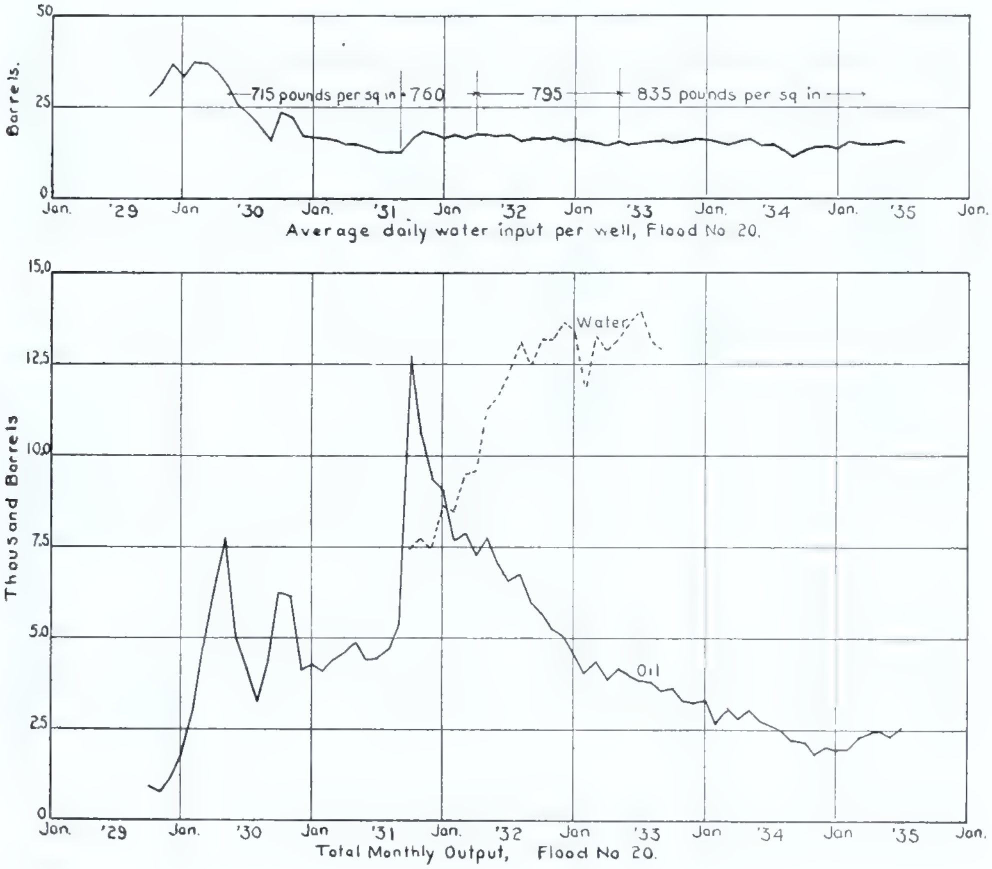


FIGURE 79. **Curves showing average daily water input per well and total monthly oil production and water output of Flood No. 20.**

The average daily oil production and water input per well and the total monthly and cumulative oil production and water input for Flood No. 20 are given in Table 106. The average daily water input per well and the total monthly oil production are shown graphically in Figure 79. The water output was gauged only between October 1931 and September 1933. This portion is shown in Figure 79.

Table 106. Average daily oil production and water input per well and total monthly and cumulative oil production and water input of Flood No. 20, in barrels.

	Oil production		Water input			Oil production		Water input	
Date	Av. daily per well	No. of wells	Total monthly	Cumulative	Date	Av. daily per well	No. of wells	Total monthly	Cumulative
1929					1929				
Oct.	.86	34	903	903	Oct	28.34	35	25,788	25,788
Nov.	.63	40	1,754	1,657	Nov.	31.87	40	38,249	64,037
Dec.	.85	44	1,161	2,818	Dec.	36.68	40	45,488	109,525
1930					1930				
Jan.	1.37	44	1,872	4,690	Jan.	32.83	49	49,868	159,393
Feb.	2.28	48	3,060	7,750	Feb.	37.22	49	51,070	210,463
Mar.	3.19	48	4,751	12,501	Mar.	36.99	49	56,196	266,659
Apr.	4.44	47	6,263	18,764	Apr.	34.35	49	50,506	317,165
May	4.55	55	7,757	26,521	May	30.69	49	46,631	363,796
June	3.01	56	5,056	31,577	June	25.12	49	36,931	400,727
July	2.11	64	4,186	35,763	July	22.44	49	34,084	434,811
Aug	1.68	61	3,176	38,939	Aug.	19.47	50	30,183	464,994
Sept.	2.55	58	4,431	43,370	Sept.	16.00	64	30,721	495,715
Oct.	3.63	56	6,296	49,666	Oct.	23.63	64	46,874	542,589
Nov.	3.95	52	6,168	55,834	Nov.	22.18	64	42,596	585,185
Dec.	2.67	50	4,141	59,975	Dec.	17.56	64	34,831	620,016
1931					1931				
Jan.	2.73	50	4,232	64,207	Jan.	16.80	64	33,325	653,341
Feb.	2.93	50	4,102	68,309	Feb.	16.21	64	29,042	682,383
Mar.	2.88	50	4,465	72,774	Mar.	15.90	64	31,541	713,924
Apr.	3.07	50	4,597	77,371	Apr.	14.90	64	28,619	742,543
May	3.15	50	4,877	82,248	May	14.55	64	28,875	771,418
June	2.91	50	4,365	86,613	June	13.43	64	25,795	797,213
July	2.85	50	4,415	91,028	July	12.48	64	24,760	821,973
Aug.	2.99	50	4,638	95,666	Aug.	12.81	64	25,412	847,385
Sept.	3.62	50	5,436	101,102	Sept.	12.73	64	24,453	871,838
Oct.	8.23	50	12,755	113,857	Oct.	16.50	64	32,743	904,581
Nov.	7.02	50	10,532	124,389	Nov.	18.18	64	34,907	939,488
Dec.	6.03	50	9,345	133,734	Dec.	17.92	64	35,546	975,034
1932					1932				
Jan.	5.86	50	9,085	142,819	Jan.	16.42	64	32,581	1,007,615
Feb.	5.31	50	7,694	150,513	Feb.	17.37	64	32,237	1,039,852
Mar.	5.09	50	7,885	158,398	Mar.	16.60	64	32,927	1,072,779
Apr.	4.84	50	7,256	165,654	Apr.	17.25	64	33,117	1,105,896
May	5.00	50	7,748	173,402	May	17.60	64	34,920	1,140,816
June	4.68	50	7,016	180,418	June	17.05	64	32,730	1,173,546
July	4.24	50	6,565	186,983	July	17.22	64	34,157	1,207,703
Aug.	4.36	50	6,752	193,735	Aug.	15.95	64	31,649	1,239,352
Sept.	4.00	50	5,995	199,730	Sept.	16.22	64	31,151	1,270,503
Oct.	3.69	50	5,724	205,454	Oct.	16.11	64	31,966	1,302,469
Nov.	3.49	50	5,248	210,702	Nov.	16.39	64	31,467	1,333,936
Dec.	3.27	50	5,070	215,772	Dec.	15.92	64	31,586	1,365,522
1933					1933				
Jan.	2.96	50	4,587	220,359	Jan.	16.01	64	31,773	1,397,295
Feb.	2.86	50	4,043	224,402	Feb.	15.56	64	27,878	1,425,173
Mar.	2.81	50	4,368	228,770	Mar.	15.13	64	30,013	1,455,186
Apr.	2.59	50	3,897	232,667	Apr.	14.44	64	27,731	1,482,917
May	2.71	50	4,191	236,858	May	15.46	64	30,670	1,513,587
June	2.66	50	4,006	240,864	June	14.63	64	28,096	1,541,683
July	2.49	50	3,869	244,733	July	15.20	64	30,163	1,571,846
Aug.	2.49	50	3,861	248,594	Aug.	15.64	64	31,023	1,602,869
Sept.	2.38	50	3,570	252,164	Sept.	15.78	64	30,307	1,633,176
Oct.	2.35	50	3,638	255,802	Oct.	15.21	64	30,181	1,663,357
Nov.	2.21	50	3,308	259,110	Nov.	15.91	64	30,545	1,693,902
Dec.	2.10	50	3,254	262,364	Dec.	16.35	64	32,429	1,726,331
1934					1934				
Jan.	2.14	50	3,318	265,682	Jan.	16.26	64	32,255	1,758,586
Feb.	1.92	50	2,686	268,368	Feb.	15.76	64	28,243	1,786,829
Mar.	1.96	50	3,042	271,410	Mar.	14.77	64	29,308	1,816,137
Apr.	1.87	50	2,800	274,210	Apr.	15.87	64	30,476	1,846,613
May	1.94	50	3,011	277,221	May	16.33	64	32,406	1,879,019
June	1.81	50	2,713	279,934	June	14.53	64	27,896	1,906,915
July	1.70	50	2,634	282,568	July	14.95	64	29,658	1,936,573
Aug.	1.64	50	2,538	285,106	Aug.	13.14	64	26,072	1,962,645
Sept.	1.49	50	2,232	287,338	Sept.	11.26	64	21,624	1,984,269
Oct.	1.42	50	2,206	289,544	Oct.	13.13	64	26,063	2,010,332
Nov.	1.25	50	1,871	291,415	Nov.	14.15	64	27,183	2,037,515
Dec.	1.30	50	2,016	293,431	Dec.	14.28	64	28,330	2,065,845
1935					1935				
Jan.	1.26	50	1,953	295,384	Jan.	13.77	64	27,315	2,093,160
Feb.	1.36	51	1,943	297,327	Feb.	15.56	64	27,895	2,121,055
Mar.	1.42	52	2,285	299,612	Mar.	14.76	64	29,279	2,150,334
Apr.	1.52	53	2,415	302,027	Apr.	14.64	64	28,106	2,178,440
May	1.50	53	2,474	304,501	May	14.70	64	29,196	2,207,636
June	1.46	54	2,361	306,862	June	15.13	64	29,058	2,236,694
July	1.54	54	2,582	309,444	July	15.32	64	30,387	2,267,081

Flood No. 21

Flood No. 21 is a five-spot development covering an area of approximately 140 acres in the Bradford pool northeast of South Bradford. The distance between intake wells is about 230 feet and between intake and producing wells, 162 feet. Slightly higher pressures were applied than in Flood No. 20.

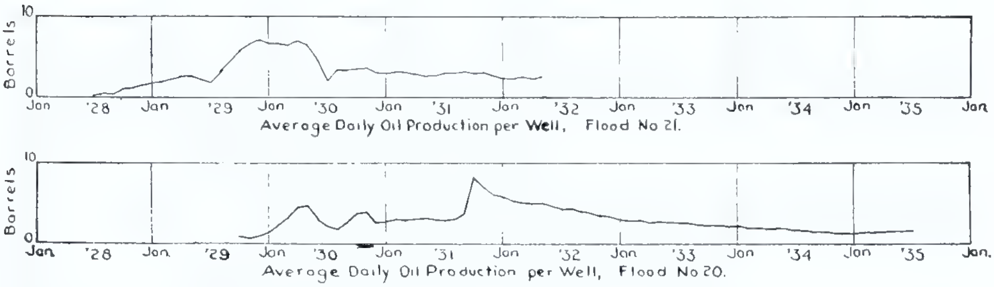
Table 107. Average daily oil production per well of Floods Nos. 20 and 21, by months.

Flood 20

Date	No. wells	Bbls.
1929		
Oct.	34	.86
Nov.	40	.63
Dec.	44	.85
1930		
Jan.	44	1.37
Feb.	48	2.28
Mar.	48	3.19
Apr.	47	4.44
May	55	4.55
June	56	3.01
July	64	2.11
Aug.	61	1.68
Sept.	58	2.55
Oct.	56	3.63
Nov.	52	3.95
Dec.	50	2.67
1931		
Jan.	50	2.73
Feb.	50	2.93
Mar.	50	2.88
Apr.	50	3.07
May	50	3.15
June	50	2.91
July	50	2.85
Aug.	50	2.99
Sept.	50	3.62
Oct.	50	8.23
Nov.	50	7.02
Dec.	50	6.03
1932		
Jan.	50	5.86
Feb.	50	5.31
Mar.	50	5.09
Apr.	50	4.84
May	50	5.00
June	50	4.68
July	50	4.24
Aug.	50	4.36
Sept.	50	4.00
Oct.	50	3.69
Nov.	50	3.49
Dec.	50	3.27
1933		
Jan.	50	2.96
Feb.	50	2.86
Mar.	50	2.81
Apr.	50	2.59
May	50	2.71
June	50	2.66
July	50	2.49
Aug.	50	2.49
Sept.	50	2.38
Oct.	50	2.35
Nov.	50	2.21
Dec.	50	2.10
1934		
Jan.	50	2.14
Feb.	50	1.92
Mar.	50	1.96
Apr.	50	1.87
May	50	1.94
June	50	1.81
July	50	1.70
Aug.	50	1.64
Sept.	50	1.49
Oct.	50	1.42
Nov.	50	1.25
Dec.	50	1.30
1935		
Jan.	50	1.26
Feb.	51	1.36
Mar.	52	1.42
Apr.	53	1.52
May	53	1.50
June	54	1.46
July	54	1.54

Flood 21

Date	No. wells	Bbls.
1928		
July	25	.29
Aug.	36	.45
Sept.	70	.40
Oct.	104	.95
Nov.	118	1.18
Dec.	122	1.37
1929		
Jan.	123	1.64
Feb.	123	1.92
Mar.	123	2.14
Apr.	123	2.46
May	123	2.59
June	123	2.22
July	123	.93
Aug.	123	3.09
Sept.	123	4.25
Oct.	123	5.81
Nov.	123	6.46
Dec.	122	6.98
1930		
Jan.	122	6.62
Feb.	122	6.59
Mar.	122	6.42
Apr.	122	6.91
May	122	6.45
June	122	4.68
July	123	2.02
Aug.	123	3.54
Sept.	123	3.35
Oct.	123	3.52
Nov.	123	3.51
Dec.	123	3.06
1931		
Jan.	123	2.99
Feb.	123	3.17
Mar.	123	3.07
Apr.	123	2.80
May	123	2.68
June	123	2.69
July	123	2.88
Aug.	123	2.95
Sept.	123	3.17
Oct.	123	3.10
Nov.	123	2.99
Dec.	121	2.60
1932		
Jan.	117	2.32
Feb.	116	2.13
Mar.	116	2.39
Apr.	116	2.21
May	116	2.40



Average Daily Oil Production per Well, Flood No 21.

Average Daily Oil Production per Well, Flood No 20.

FIGURE 80. Curves showing average daily oil production per well by months of Floods Nos. 20 and 21.

During the first 47 weeks, the average recovery per acre of Flood No. 21 had reached 3,911 barrels as compared to 3,896 barrels in Flood No. 20. At the end of that period, the average daily oil output per well for Flood No. 21 was 2.40 barrels and for Flood No. 20, 2.49 barrels. The average thickness of oil-bearing sandstone under the tract on which Flood No. 21 is located is estimated at 47 feet as compared to 42 feet in the case of Flood No. 20. The production of Flood No. 21 was curtailed after its peak had been passed and that of Flood No. 20 was curtailed before its peak was reached. The recoveries obtained by the two different operators near South Bradford on tracts whose sand conditions are very similar are almost identical. The average daily oil production per well by months of Floods Nos. 20 and 21 is given in Table 107 and is shown graphically in Figure 80.

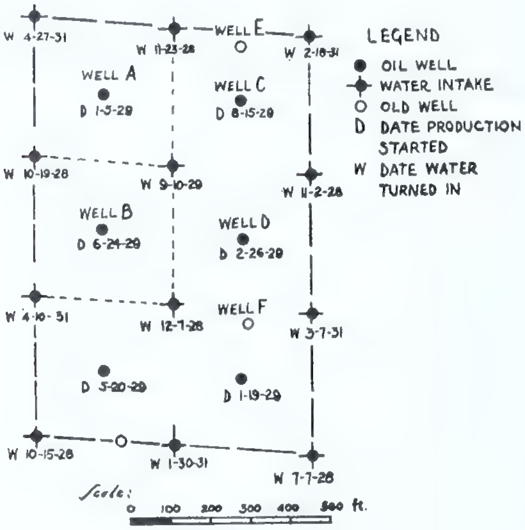


FIGURE 81. Map of Flood No. 22.

Flood No. 22

Flood No. 22 is part of a five-spot development in the southeastern lobe of the Bradford pool near the head of Kendall Creek. The distance between water intake wells is 345 feet and between water intake and oil wells, 244 feet. The intake wells originally were piped for subsurface water. During 1931 a pressure plant was erected on the property and since July 1931 all water has been admitted at the top. The pump pressure is such as to give approximately 1,200 pounds per square inch at the face of the sand in the intake wells. Production was curtailed at intervals during 1930, 1931 and 1932.

The six units shown in Figure 81, covering 16.38 acres, had yielded at the end of June 1935 a total of 33,821 barrels of oil or an average of 2,065 barrels per acre. According to the drillers' records, the sand body has an average thickness of 45 feet. It is estimated that 55 percent or 25 feet of this is oil-bearing sandstone, making the recovery 83 barrels per acre-foot. The oil and water output and the water output to oil ratios of six of the wells are given in Table 108. It will be noted that during June 1935 the average daily oil production of the wells and their water output to oil ratios was such as to indicate that the above figures will be appreciably increased before the economic limit is reached.

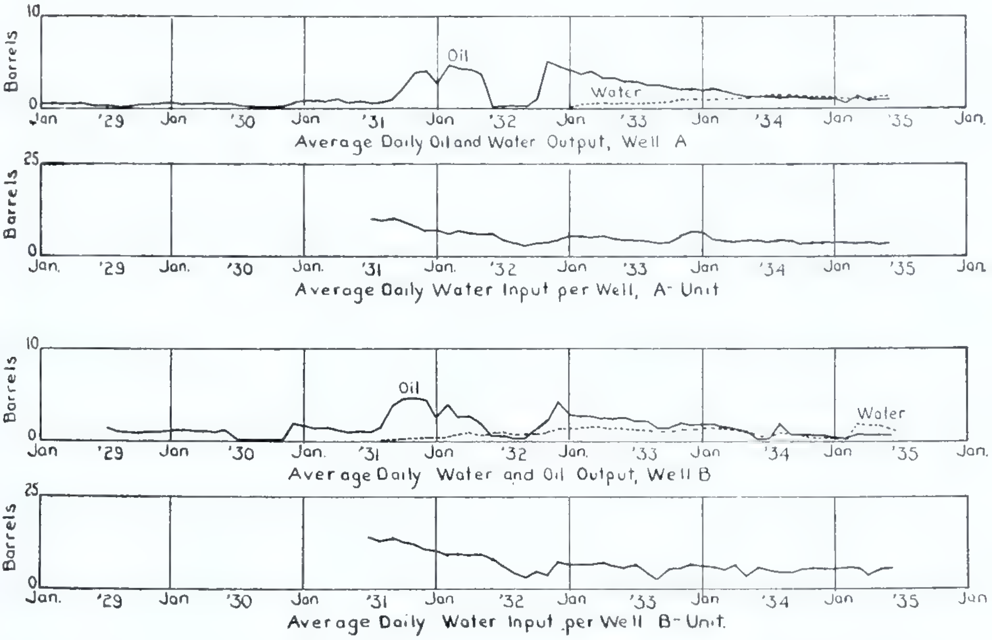


FIGURE 82. Curves showing average daily oil and water production and water input by months of A and B units in Flood No. 22.

Table 108. Oil and water output and water output to oil ratios of six wells in Flood No. 22 to the end of June 1935.

				Average daily production June 1935		
Well	Oil production Bbls.	Water output Bbls.	Water output to oil ratio	Oil Bbls.	Water Bbls.	Water output to oil ratio
A	3,596	889	.25	.95	1.21	1.27
B	3,253	1,302	.40	.64	1.24	1.94
C	5,836	5,128	.88	1.93	6.10	3.16
D	4,287	1,500	.35	1.58	1.90	1.20
E	1,366	1,322	.97	.44	1.76	4.00
F	2,487	8,144	3.26	1.00	8.11	8.11

The average daily and the cumulative oil and water production of wells A and B and the water input for the A and B units by months are given in Tables 109 and 110. The average daily production and water input are shown graphically in Figure 82. The relation of fluid output to input for the two units by years is given in Table 111. The water input has been calculated on the assumption that the water is uniformly distributed in the four quadrants around each intake well. The water input for the A and B units during the first year was 6,866 barrels or 1,258 barrels per acre, which is equivalent to two inches of water. Flood No. 22 is an example of a flooding operation in an area in which the Bradford Third sand has an exceptionally low permeability. The rate of production, therefore, has been low as compared to the other intensive floods already discussed. This has been further accentuated by the fact that the distance between intake and producing wells is also greater.

Table 109. Average daily and cumulative oil and water production of well A and water input for A-unit in Flood No. 22 by months, in barrels.

	Oil prod.		Water prod.		Water input	
Date	Daily	Cumu.	Daily	Cumu.	Daily	Cumu.
1929						
Jan.	.67	21				
Feb.	.69	40				
Mar.	.52	56				
Apr.	.45	70				
May	.43	83				
June	.34	93				
July	.38	105				
Aug.	.36	116				
Sept.	.33	126				
Oct.	.41	139				
Nov.	.44	152				
Dec.	.50	167				
1930						
Jan.	.54	184				
Feb.	.52	199				
Mar.	.46	213				
Apr.	.57	230				
May	.54	247				
June	.54	263	.02	1		
July	.25	271	.01	1		
Aug.		271	.00			
Sept.	.14	275	.27	9		
Oct.	.03	276	.29	18		
Nov.	.14	280				
Dec.	.70	302				
1931						
Jan.	.85	328				
Feb.	.90	353				
Mar.	.79	378	.01	18		
Apr.	.88	404				
May	.64	424				
June	.75	447				
July	.68	468	.01	19	10.25	318
Aug.	.67	489			9.75	620
Sept.	1.08	521	.01	19	10.25	928
Oct.	2.34	593	.01	19	9.25	1214
Nov.	3.98	713			8.25	1462
Dec.	4.04	838			7.00	1679
1932						
Jan.	2.78	924	.06	21	7.00	1896
Feb.	4.76	1062			6.00	2070
Mar.	4.41	1199	.01	21	7.00	2287
Apr.	4.27	1327			6.25	2474
May	3.77	1444			6.00	2660
June		1444			6.00	2840
July	.09	1447			4.50	2980
Aug.	.04	1448			3.50	3088
Sept.	.10	1451			2.75	3170
Oct.	1.04	1483	.08	24	3.50	3279
Nov.	5.10	1636			3.75	3391
Dec.	4.67	1781	.35	35	4.50	3531
1933						
Jan.	4.31	1915	.30	44	5.50	3701
Feb.	3.98	2026	.43	56	5.75	3862
Mar.	4.09	2153	.53	73	5.25	4025
Apr.	3.35	2253	.67	93	5.50	4190
May	3.31	2356	.58	111	5.00	4345
June	2.97	2445	.69	131	4.50	4480
July	2.86	2534	.59	150	4.25	4612
Aug.	2.51	2612	.70	171	4.00	4736
Sept.	2.48	2686	.71	193	3.75	4848
Oct.	2.36	2758	.75	216	4.00	4972
Nov.	2.11	2821	.90	243	5.50	5137
Dec.	2.22	2890	.88	270	6.50	5339
1934						
Jan.	2.02	2953	.95	300	6.50	5540
Feb.	2.06	3010	.97	327	4.75	5673
Mar.	1.88	3069	1.03	359	4.25	5805
Apr.	1.53	3115	1.11	392	4.00	5925
May	1.40	3158	1.21	430	4.25	6057
June	1.33	3198	1.20	466	4.25	6184
July	1.31	3238	1.27	505	4.00	6308
Aug.	1.21	3276	1.19	542	4.25	6440
Sept.	1.27	3314	1.26	580	4.25	6567
Oct.	1.13	3349	1.28	619	3.25	6668
Nov.	1.08	3381	1.15	654	3.75	6781
Dec.	1.06	3414	1.11	688	3.75	6897
1935						
Jan.	1.05	3447	1.00	719	3.75	7013
Feb.	.48	3460	.96	746	3.75	7118
Mar.	1.43	3505	1.12	781	3.50	7227
Apr.	1.05	3536	1.18	816	3.75	7339
May	1.02	3568	1.19	853	3.50	7448
June	.95	3596	1.21	889	3.75	7560

Table 110. Average daily and cumulative oil and water production of well B and water input for B-unit in Flood No. 22 by months, in barrels.

	Oil prod.		Water prod.		Water input	
Date	Daily	Cumu.	Daily	Cumu.	Daily	Cumu.
1929						
July	1.49	46				
Aug.	1.06	79	.01			
Sept.	1.01	109	.01	1		
Oct.	.98	140				
Nov.	1.02	170	.01	1		
Dec.	.93	199	.01	1		
1930						
Jan.	1.03	231				
Feb.	1.11	272				
Mar.	1.04	304				
Apr.	1.03	335				
May	.93	364				
June	1.05	396				
July	.07	398				
Aug.	.09	401				
Sept.	0.00					
Oct.	0.00					
Nov.	0.00					
Dec.	1.87	459	.04	2		
1931						
Jan.	1.60	508				
Feb.	1.41	548				
Mar.	1.40	591				
Apr.	1.05	623				
May	.88	650	.02	3		
June	.99	680				
July	.83	705			14.00	435
Aug.	1.52	752	.05	5	13.25	846
Sept.	3.74	865	.18	10	13.75	1261
Oct.	4.59	1007	.24	17	12.75	1653
Nov.	4.77	1150	.24	25	12.00	2016
Dec.	4.44	1288	.23	32	10.50	2341
1932						
Jan.	2.46	1364	.21	38	10.25	2659
Feb.	3.95	1478	.46	52	9.25	2927
Mar.	2.55	1557	.75	75	9.50	3222
Apr.	2.73	1636	.84	100	9.25	2499
May	2.01	1702	.66	121	9.25	3786
June	.53	1718	.75	143	8.00	4026
July	.50	1733	.87	170	6.50	4228
Aug.	.20	1739	.73	193	4.00	4352
Sept.	.24	1746	.64	212	3.00	4442
Oct.	1.27	1786	.79	236	4.75	4589
Nov.	2.41	1858	.87	262	3.75	4701
Dec.	4.35	1993	1.27	302	7.25	4926
1933						
Jan.	2.86	2086	1.41	346	6.75	5135
Feb.	2.76	2159	1.41	385	6.75	5324
Mar.	2.56	2238	1.46	430	6.75	5534
Apr.	2.43	2311	1.44	473	7.00	5744
May	2.39	2385	1.42	518	6.25	5937
June	2.45	2459	1.41	560	6.75	6110
July	2.14	2525	1.32	601	6.50	6311
Aug.	2.04	2588	1.22	639	4.75	6459
Sept.	1.50	2633	1.14	673	2.75	6541
Oct.	1.48	2679	1.00	704	5.50	6712
Nov.	1.89	2736	1.32	743	5.50	6877
Dec.	1.80	2792	1.41	787	6.50	7078
1934						
Jan.	1.77	2847	1.41	831	6.25	7272
Feb.	1.77	2896	1.45	871	6.00	7440
Mar.	1.52	2943	1.29	911	5.25	7600
Apr.	1.26	2981	1.26	949	6.50	7795
May	1.06	3014	1.15	985	3.25	7896
June	.08	3016	.52	1000	5.75	8068
July			.19	1006	5.00	8223
Aug.	1.94	3077	.98	1037	4.50	8363
Sept.	.77	3100	.73	1059	4.50	8498
Oct.	.64	3119	.55	1076	5.25	8661
Noc.	.62	3138	.24	1083	5.75	8833
Dec.	.51	3154	.28	1092	5.50	9004
1935						
Jan.	.42	3167	.30	1101	5.50	9174
Feb.	.33	3176	.12	1104	5.75	9335
Mar.	.62	3195	1.83	1161	5.50	9506
Apr.	.63	3214	1.77	1214	3.75	9618
May	.63	3234	1.65	1265	5.25	9781
June	.64	3253	1.24	1302	5.50	9946

Table 111. Relation of fluid output to input for A and B units in Flood No. 22 by years.

Year	Oil production, Bbls.	Water output, Bbls.	Total fluid produced, Bbls.	Water input Bbls.	Water input to oil ratio	Water output to oil ratio
1931-32	2,035	143	2,178	6,866	3.32	.07
1932-33	1,742	527	2,269	3,723	2.14	.03
1933-34	1,310	775	2,085	3,663	2.80	.59
1934-35	635	726	1,361	3,254	5.12	1.14
Total	5,722	2,171	7,893	17,506	3.06	.38

Flood No. 23

Flood No. 23 represents three units of a five-spot development near the western margin of the Knapp Creek dome gas cap at the head of Pennbrook Run. In the case of the A and B units, the distance between intake wells is 251 feet and between intake and producing wells, 178 feet. Unfiltered water obtained from the alluvium of Pennbrook Run is admitted to the intake wells at a pressure equivalent to 940 pounds per square inch at the face of the sand. The distance between wells A and D of Figure 83 is 1,400 feet. Production was curtailed at intervals during 1930 and 1931.

Wells C and D, shown in Figure 83, drain 1.9 acres. At the end of June 1935 these two wells had yielded 11,801 barrels of oil or 6,211 barrels per acre. At the end of that period well C was still producing 1.62 barrels per day and well D, 1.09 barrels. Core 3, taken from well D, contained 34.1 feet of oil-bearing sandstone with an average porosity of 14.3 percent, making the recovery 182 barrels per acre-foot. The core showed an oil content of 13,730 barrels per acre. The total recovery at the end of June 1935 represents 45 percent of this amount.

Wells A and B drain 2.9 acres and had yielded 17,246 barrels of oil by the end of June 1935 or 5,947 barrels per acre. At the end of that period well A was still producing 1.59 barrels of oil per day and well B 1.74 barrels. The drillers' records show an average thickness of 62 feet of oil pay, of which it is estimated 50 percent or 31 feet is oil-bearing sandstone, which makes the recovery 192 barrels per acre foot.

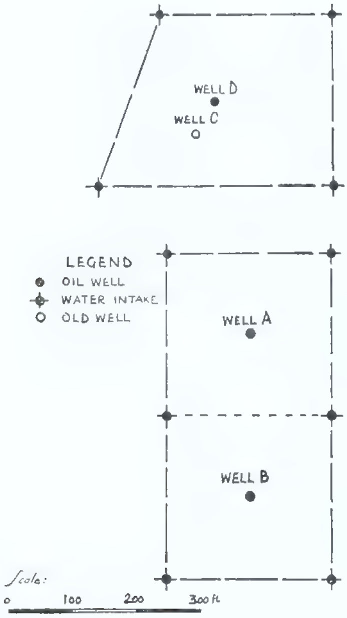


FIGURE 83. Map of Flood No. 23.

The average daily and cumulative oil production and water input for the A and B units of Flood No. 23 by months are given in Table 112. The average daily oil production and water input are also shown graphically in Figures 84 and 85 respectively. At the end of May 1935, the total water input to oil ratio for the above two units was 12.84:1. During the first year the water input for the two units was 64,504 barrels or 22,243 barrels per acre, which is equivalent to 34.4 inches of water. The water production on this property has been so large that it has not been feasible to keep a daily gauge. Although the gas pay overlying the oil pay at this locality was carefully packed off in the intake wells, large volumes of water are apparently being by-passed either through a portion of the gas pay or through some of the more permeable layers in the oil pay.

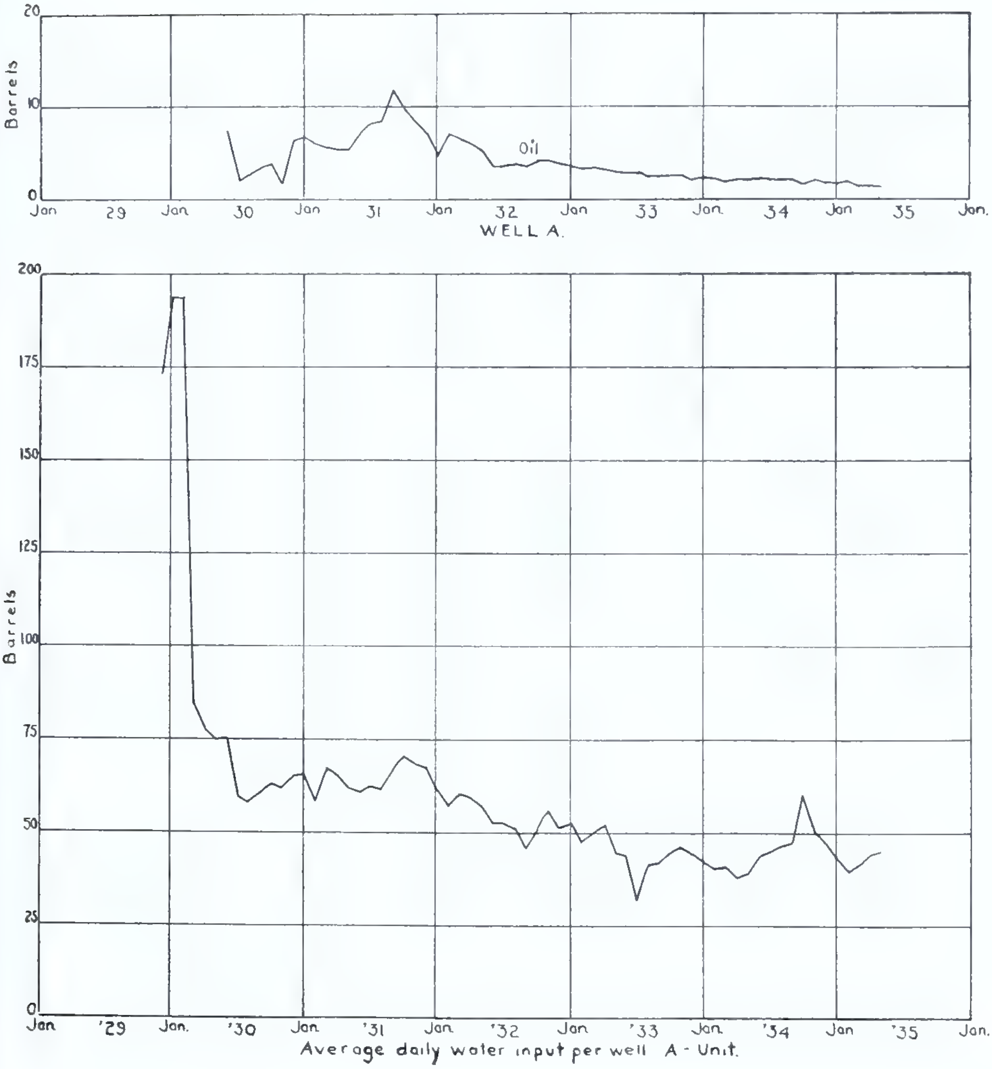


FIGURE 84. **Curves showing average daily oil production and water input by months for A unit of Flood No. 23.**

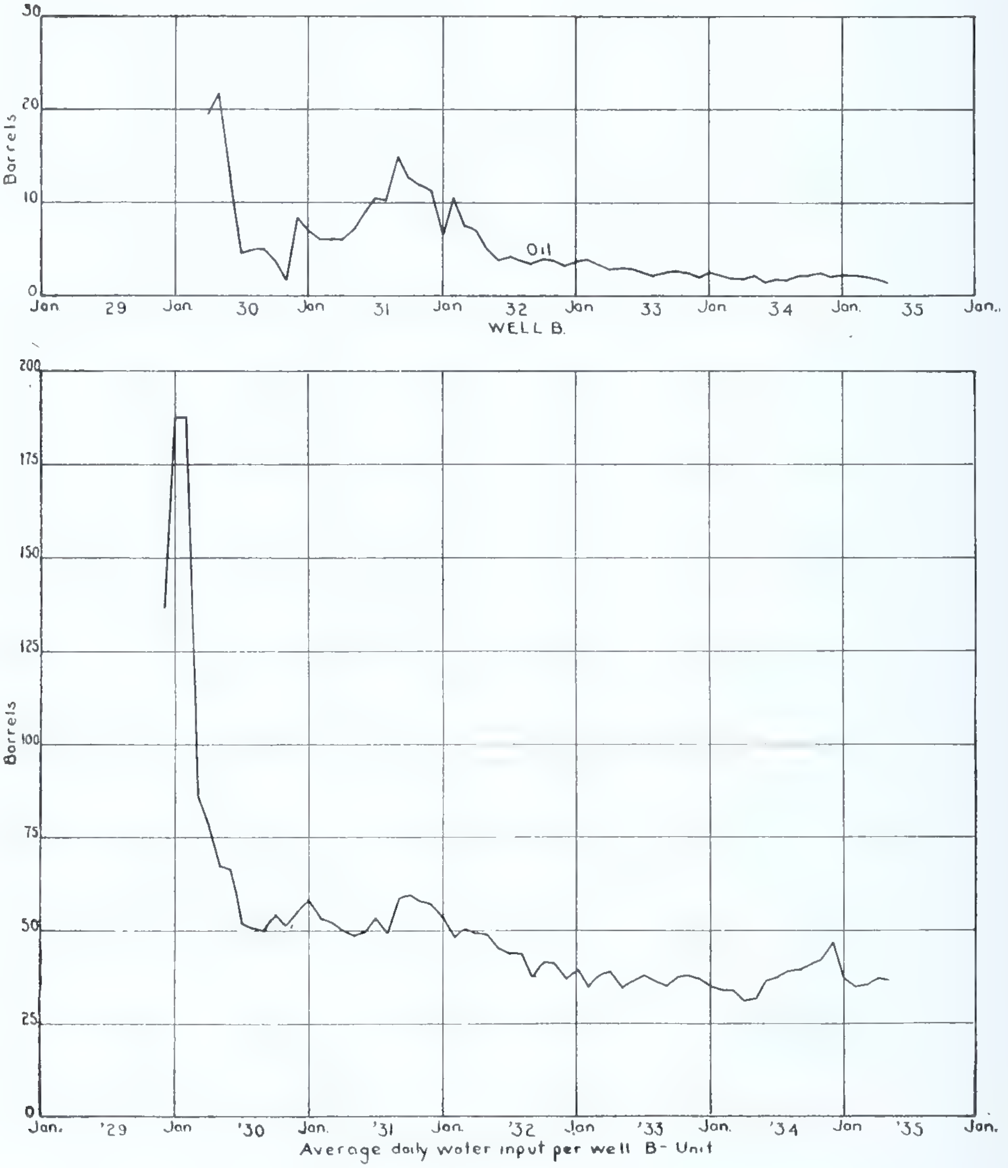


FIGURE 85. Curves showing average daily oil production and water input by months for B unit of Flood No. 23.

Table 112. Average daily and cumulative oil production and water input for A and B units of Flood No. 23 by months, in barrels.

	A-Unit			
	Oil production		Water input	
Date	Daily	Cumulative	Daily	Cumulative
1929				
Dec.			129.75	4,022
1930				
Jan.			193.50	10,021
Feb.			193.50	15,439
Mar.			84.75	18,066
Apr.			77.75	20,399
May			75.00	22,724
June	7.35	220	75.25	24,981
July	2.13	286	59.50	26,826
Aug.	2.70	370	58.25	28,631
Sept.	3.51	475	60.50	30,446
Oct.	3.66	589	63.00	32,399
Nov.	1.26	626	61.75	34,252
Dec.	6.23	820	65.25	36,275
1931				
Jan.	6.56	1,013	65.50	38,305
Feb.	5.86	1,182	58.50	39,943
Mar.	5.58	1,355	67.25	42,028
Apr.	5.25	1,513	65.25	43,985
May	5.29	1,677	62.00	45,907
June	7.04	1,888	60.75	47,730
July	8.29	2,145	62.75	49,675
Aug.	8.41	2,406	61.41	51,579
Sept.	11.63	2,755	66.50	53,574
Oct.	9.72	3,056	70.36	55,755
Nov.	8.28	3,303	68.50	57,810
Dec.	7.18	3,525	67.50	59,903
1932				
Jan.	4.54	3,666	61.75	61,817
Feb.	7.15	3,874	57.00	63,470
Mar.	6.48	4,074	60.25	65,338
Apr.	5.99	4,254	59.50	67,126
May	5.29	4,418	57.50	68,905
June	3.44	4,521	52.75	70,488
July	3.60	4,633	52.75	72,123
Aug.	3.78	4,750	51.25	73,712
Sept.	3.55	4,857	45.50	75,077
Oct.	4.06	4,982	50.25	76,634
Nov.	4.14	5,107	56.00	78,314
Dec.	3.84	5,226	51.25	79,903
1933				
Jan.	3.52	5,335	52.50	81,531
Feb.	3.35	5,429	47.50	82,861
Mar.	3.40	5,534	49.75	84,403
Apr.	3.20	5,630	52.00	85,963
May	3.09	5,726	44.75	88,350
June	2.80	5,810	44.00	88,670
July	2.84	5,898	31.75	89,654
Aug.	2.41	5,973	41.75	90,949
Sept.	2.49	6,047	42.00	92,209
Oct.	2.45	6,123	44.75	93,956
Nov.	2.54	6,199	46.25	94,983
Dec.	2.26	6,269	44.50	96,363
1934				
Jan.	2.31	6,341	42.25	97,673
Feb.	2.24	6,404	40.25	98,800
Mar.	1.93	6,464	41.00	100,071
Apr.	2.20	6,530	38.00	101,211
May	2.06	6,593	39.00	102,420
June	2.19	6,659	43.75	103,732
July	2.08	6,724	45.00	105,127
Aug.	2.08	6,788	46.50	106,569
Sept.	2.10	6,851	47.25	107,986
Oct.	1.59	6,900	60.75	109,869
Nov.	2.01	6,961	50.50	111,384
Dec.	1.88	7,019	47.25	112,849
1935				
Jan.	1.78	7,074	43.25	114,190
Feb.	1.96	7,129	39.50	115,296
Mar.	1.44	7,174	41.50	116,582
Apr.	1.57	7,221	44.25	117,910
May	1.35	7,263	45.00	119,305
June	1.59	7,310		

	B-Unit			
	Oil production		Water input	
Date	Daily	Cumulative	Daily	Cumulative
1929				
Dec.			68.25	2,116
1930				
Jan.			187.50	7,928
Feb.			187.50	13,178
Mar.			87.00	15,875
Apr.	19.54	586	78.75	18,238
May	21.93	1,266	67.25	20,323
June	12.27	1,634	66.75	22,325
July	4.48	1,773	52.00	23,937
Aug.	4.81	1,923	50.75	25,510
Sept.	5.01	2,073	50.00	27,010
Oct.	3.76	2,190	54.50	28,700
Nov.	1.60	2,238	51.75	30,252
Dec.	8.20	2,492	54.75	31,950
1931				
Jan.	7.01	2,709	58.75	33,771
Feb.	6.05	2,879	53.25	35,262
Mar.	6.13	3,069	52.50	36,890
Apr.	6.09	3,251	50.25	38,397
May	7.14	3,473	49.00	39,916
June	9.06	3,744	49.75	41,409
July	10.50	4,070	53.75	43,075
Aug.	10.11	4,383	49.16	44,599
Sept.	14.86	4,829	58.50	46,354
Oct.	12.60	5,220	59.86	48,210
Nov.	11.94	5,578	58.00	49,950
Dec.	11.40	5,931	57.25	51,725
1932				
Jan.	6.66	6,138	54.00	53,399
Feb.	8 48	6,384	48.25	54,798
Mar.	7.51	6,616	50.75	56,371
Apr.	7.07	6,827	49.75	57,864
May	5.12	6,985	49.00	59,383
June	3.92	7,103	45.25	60,740
July	4.25	7,235	44.00	62,104
Aug.	3.78	7,352	44.00	63,468
Sept.	3.55	7.458	37.25	64,586
Oct.	3.91	7,580	41.75	65,880
Nov.	3.74	7,692	41.25	67,117
Dec.	3.28	7,784	37.00	68,264
1933				
Jan.	3.64	7,897	39.50	69,489
Feb.	3.95	8,008	34.75	70,462
Mar.	3.45	8,115	38.00	71,640
Apr.	2.86	8,201	39.00	72,810
May	2.92	8,291	34.75	73,887
June	2.85	8,377	36.25	74,975
July	2.45	8,453	38.00	76,153
Aug.	2.21	8,521	36.50	77,284
Sept.	2.43	8,594	35.25	78,342
Oct.	2.77	8,680	37.25	79,496
Nov.	2.49	8,755	38.00	80,636
Dec.	1.99	8,816	37.00	81,783
1934				
Jan.	2.62	8,897	35.00	82,868
Feb.	2.22	8,960	34.00	83,820
Mar.	1.91	9,019	34.00	84,874
Apr.	1.83	9,074	31.00	85,804
May	2.25	9,142	31.75	86,789
June	1.50	9,187	36.50	87,884
July	1.81	9,243	37.50	89,046
Aug.	1.69	9,296	39.00	90,255
Sept.	2.21	9,362	39.50	91,440
Oct.	2.26	9,432	41.00	92,711
Nov.	2.61	9,510	42.25	93,979
Dec.	2.15	9,577	47.00	95,436
1935				
Jan.	2.30	9,648	37.00	96,583
Feb.	2.34	9,714	34.75	97,556
Mar.	2.14	9,780	35.25	98,648
Apr.	1.87	9,836	37.00	99,758
May	1.54	9,884	36.50	100,890
June	1.74	9,936		

Flood No. 24

Flood No. 24 is a five-spot development started late in 1929 in the extreme northeastern part of the Knapp Creek dome gas cap. The six units whose production is discussed are shown in Figure 86. The distance between water intake wells is 315 feet and between water intake and oil wells, 223 feet. Water for flooding purposes is obtained from the alluvium along the valley of Mix Creek. It is filtered. Prior to June 1931, the water was introduced into the intake wells at a pressure equivalent to 885 pounds per square inch at the face of the sand. Between June and September, 1931, this was raised to 1,335 pounds at which it has been maintained since that time. Production has at no time been intentionally curtailed.

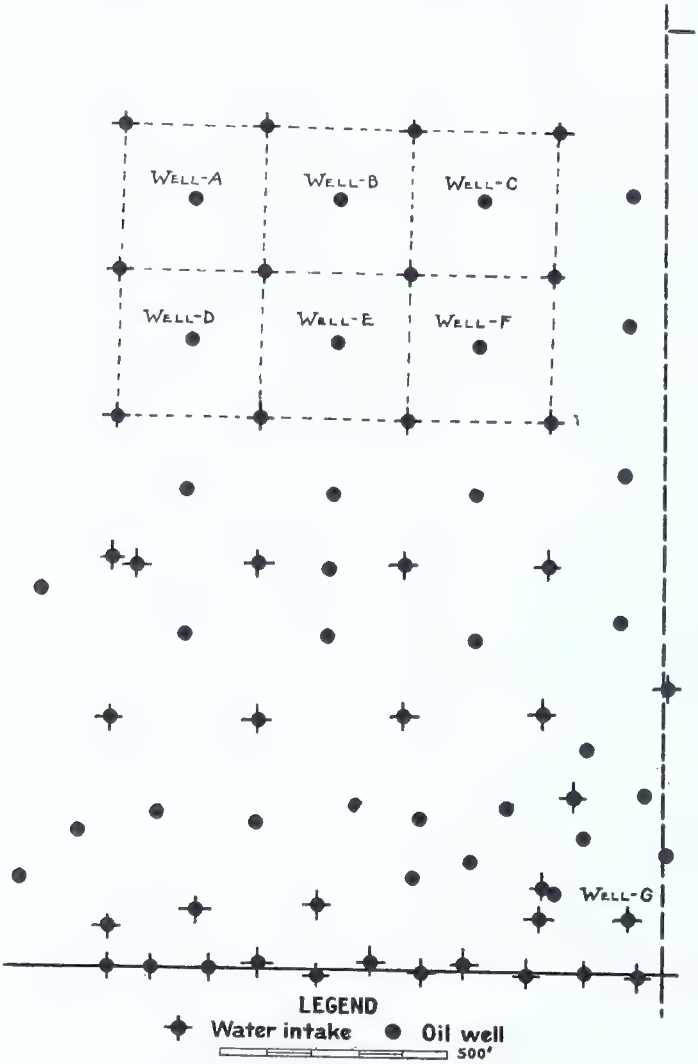


Figure 86. Map of Flood No. 24.

The six units shown in Figure 86 cover 13.67 acres. At the end of June 1934 the total oil recovery from them reached 21,012 barrels, representing an average yield of only 1,537 barrels per acre. According to the drillers' records, the oil pay has an average thickness of 28 feet. It is estimated that 79 percent or 22 feet of this is oil-bearing sandstone. The yield per acre-foot during the above period, therefore, was 70 barrels. Core 2, whose permeability profile is shown in Plate 16, came from well G of Figure 86. The oil-bearing sandstone of the oil pay in this core had an average porosity of 13.9 percent and a saturation of 29 percent. On this basis, the 22 feet of oil-bearing sandstone underlying these six units would have an average oil content of 6,880 barrels

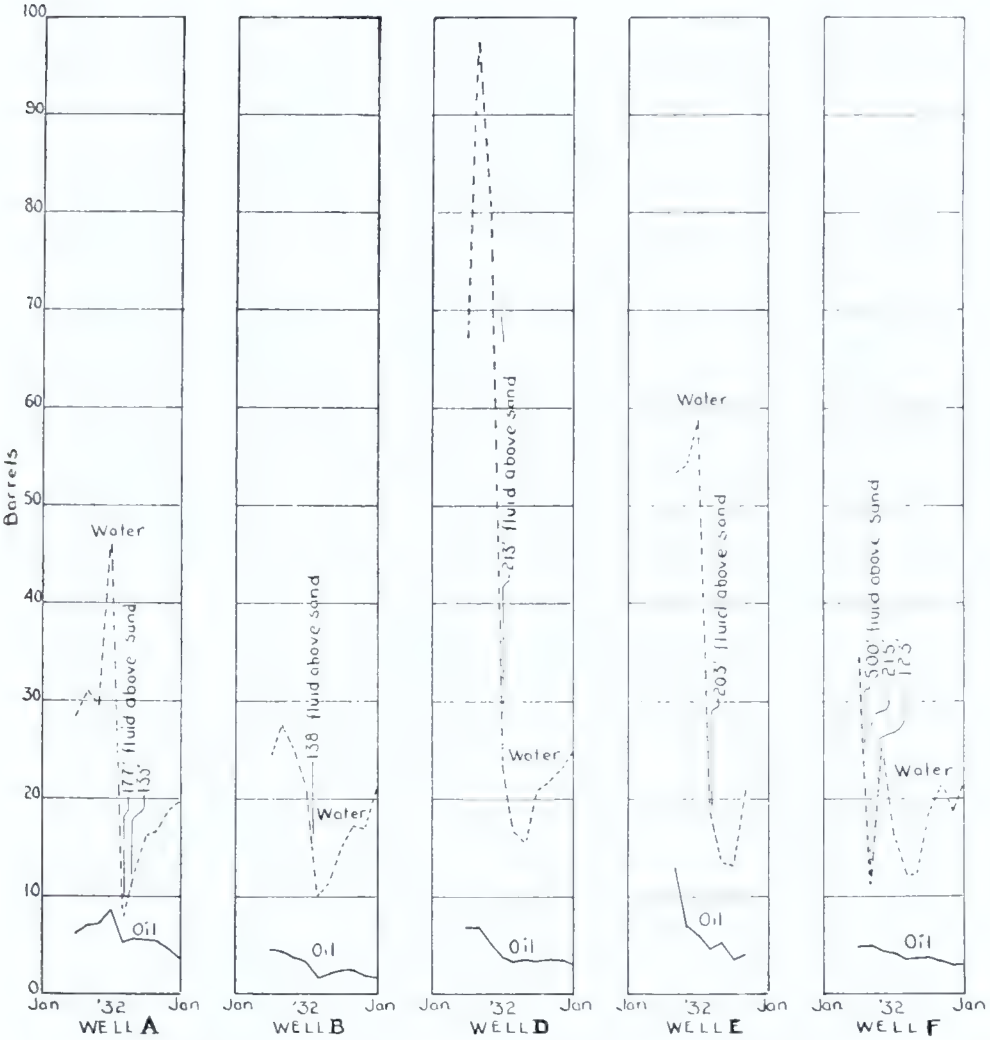


FIGURE 87. Curves showing effects of back pressure on the production of wells A, B, D, E. and F of Flood No. 24.

per acre. The 1,537 barrels recovered at the end of June 1934 represent 22 percent of this amount. At the end of June 1934, the average daily oil production per well for the six wells was still 1.44 barrels. The above figures will, therefore, be increased somewhat before the economic limit is reached.

On the assumption that the water introduced into each intake well of a five-spot unit is equally divided among the four quadrants about the well, the total water input for the six units at the end of June 1934 had reached 545,860 barrels, making the water input to oil ratio 26:1. The water input for the first year was 114,160 barrels or 8,351 barrels per acre, which is equivalent to 13 inches.

Both the water input and the water output to oil ratios on this property are unusually high. In 1932 and 1933, the tubing in the producing wells was raised so as to maintain a column of fluid in the wells which would exert a back pressure on the face of the sand. It was thought that possibly in this way the by-passing of the water through the more permeable layers of sand might be cut down without seriously affecting the oil production from the less

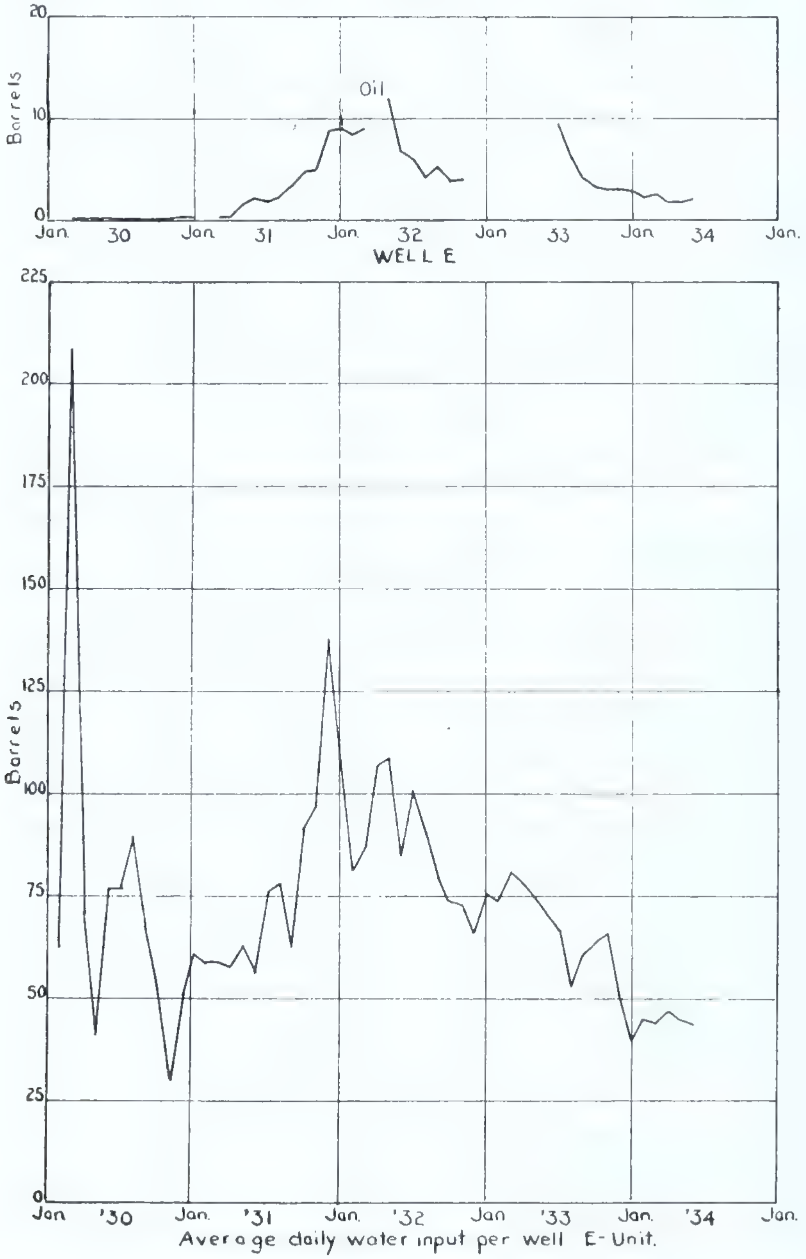


Figure 88. Curves showing average daily oil production and water input by months for E unit of Flood No. 24.

permeable ones. The results of these experiments have been summarized in Table 113 and are shown graphically in Figure 87. It will be noted that while the water output to oil ratio was materially reduced, at least temporarily, by the back pressure, the oil production was also very noticeably curtailed and the water output to oil ratio soon started to rise again. It was, therefore, concluded that this method was not effective in solving the problem encountered on this tract.

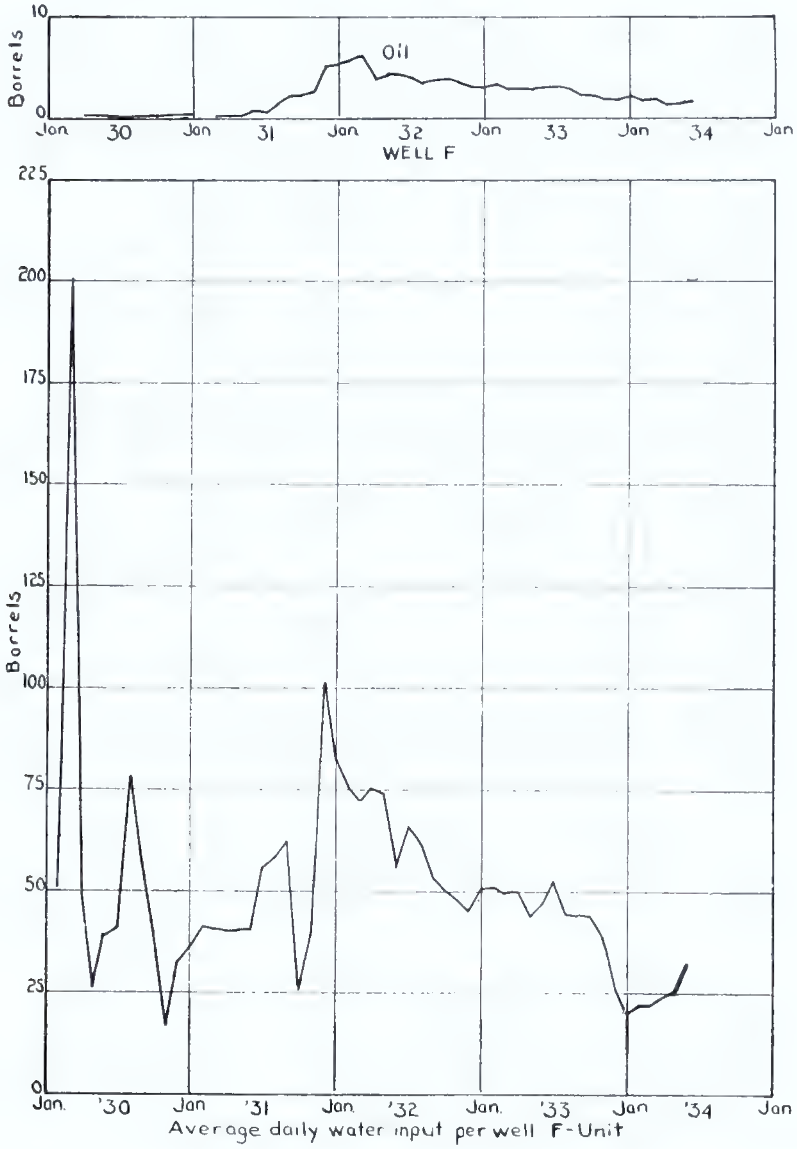


FIGURE 89. **Curves showing average daily oil production and water input by months for F unit of Flood No. 24.**

The average daily and cumulative oil production and water input for the E and F units of Flood No. 24 by months are given in Table 114. The average daily oil production and water input are also shown graphically in Figures 88 and 89 respectively.

Table 113. Effects of back pressure on the production of wells A, B, D, E and F of Flood No. 24, in barrels.

Date	Well A				Well B				Well D				Well E				Well F			
	Oil production		Water output		Oil production		Water output		Oil production		Water output		Oil production		Water output		Oil production		Water output	
	Aver. daily	Total monthly	Aver. daily	Total monthly	Aver. daily	Total monthly	Aver. daily	Total monthly	Aver. daily	Total monthly	Aver. daily	Total monthly	Aver. daily	Total monthly	Aver. daily	Total monthly	Aver. daily	Total monthly	Aver. daily	Total monthly
1932																				
April	6.15	178	28.35	851	4.51	131	24.39	732	6.79	204	67.10	2,013	13.01	377	53.69	1,556	4.95	119	34.45	838
May	7.02	218	31.04	962	4.24	132	27.74	860	6.86	213	97.42	3,020	7.03	211	54.21	1,626	5 03	136	11.39	308
June	7.30	219	30.69	921	3.77	113	25.00	750	5.27	158	80.18	2,406	6.05	188	58.73	1,821	4.36	131	25.41	763
July	8.54	265	46.15	1,431	3.43	96	20.92	586	3.58	116	23.65	710	4.49	135	18.66	560	4.17	125	16.12	484
August	5.29	159	7.46	224	1.75	53	9.99	298	3.21	96	16.51	495	5.27	158	13.63	409	3.64	109	12.15	365
Sept.	5.84	175	12.50	375	2.15	65	11.70	351	3.55	1.07	15.46	464	3.64	123	13.29	409	3.74	112	12.23	367
Oct.	5.72	177	16.19	502	2.25	70	15.21	472	3.29	102	20.73	643	3.99	120	20.98	630	3.82	118	18.69	579
Nov.	5.34	160	16.67	500	2.27	68	17.29	518	3.49	105	21.80	654					3.44	104	21.47	644
Dec.	4.51	140	18.87	585	1.95	61	16.86	523	3.49	108	22.89	709					3.05	95	18.64	579
1933																				
Jan.	3.61	112	19.86	616	1.75	54	21.10	656	2.88	89	24.54	761					3.16	98	22.16	687

On Aug. 3, 1932, tubing raised so as to have 177 feet of fluid above sand.

On Aug. 22, 1932, tubing lowered so as to have 133 feet of fluid above sand.

On Oct. 8, 1932, tubing lowered so as to have 89 feet of fluid above sand.

Water output to oil ratio:
3-26-32 to 3-3-32=5.08:1
8- 4-32 to 8-22-32=0.81:1
8-23-32 to 10- 8-32=2.02:1
10- 9-32 to 2- 5-33=3.91:1

On July 15, 1932, tubing raised so as to have 138 feet of fluid above sand.

Water output to oil ratio:
3-26-32 to 7-15-32=6.38:1
7-16-32 to 2- 5-32=7.10:1

On June 30, 1932, tubing raised so as to have 213 feet of fluid above sand.

Water output to oil ratio:
3-26-32 to 6-30-32=12.75:1
7- 1-32 to 2- 5-33= 6.17:1

On Aug. 5, 1932, tubing raised so as to have 203 feet of fluid above sand.

Stopped pumping Dec. 2, 1932.

On Jan. 1, 1933, raised a pressure on surrounding 4 intake wells 300 pounds per square inch during day in an attempt to flow production of well. Unsuccessful.

By March 8 fluid level in well had risen 1,180 feet. Top of sand 1,474 feet.

Water output to oil ratio:
5-3-32 to 8-5-32=6.43:1
8-6-32 to 12-2-32=3.79:1

On April 14, 1932 tubing raised so as to have 500 feet of fluid above sand.

On April 23, 1932, tubing lowered so as to have 215 feet of fluid above sand.

On May 19, 1932, tubing lowered so as to have 123 feet of fluid above sand.

Water output to oil ratio:
3-26-32 to 4-14-32—15.05:1
4-23-32 to 5-19-32— 1.91:1
5-20-32 to 2- 5-33= 4.91:1

Table 114. Average daily and cumulative oil production and water input for E and F units of Flood No. 24 by months, in barrels.

E-Unit

	Oil production		Water input	
Date	Daily	Cumulative	Daily	Cumulative
1930				
Feb.			15.7	439
Mar.	.21	6	52.4	2,063
Apr.	.19	12	53.4	3,666
May	.24	20	30.9	4,625
June	.10	23	57.9	6,362
July	.06	24	58.4	8,174
Aug.	.10	28	90.2	10,971
Sept.	.11	31	68.8	13,036
Oct.	.15	35	53.4	14,692
Nov.	.13	39	30.0	15,592
Dec.	.29	48	51.3	17,182
1931				
Jan.	.22	55	61.2	19,078
Feb.			59.1	20,732
Mar.	.23	62	59.3	22,570
Apr.	.29	71	58.1	24,312
May	1.72	124	63.7	26,287
June	2.12	188	57.3	28,007
July	1.83	245	38.3	29,194
Aug.	2.28	316	39.2	30,408
Sept.	3.32	415	47.9	31,847
Oct.	4.79	564	92.9	34,727
Nov.	4.95	712	97.7	37,659
Dec.	8.90	988	138.0	41,939
1932				
Jan.	9.01	1,268	111.2	45,388
Feb.	8.39	1,511	81.1	47,740
Mar.	9.08	1,720	87.8	50,461
Apr.			107.6	53,690
May	12.17	2,097	109.6	57,087
June	7.04	2,308	85.3	59,646
July	6.05	2,495	101.5	62,791
Aug.	4.35	2,630	91.4	65,623
Sept.	5.28	2,789	80.1	68,028
Oct.	3.96	2,911	74.1	70,324
Nov.	3.99	3,031	73.8	72,539
Dec.	2.88	3,037	66.8	74,609
1933				
Jan.			76.8	76,990
Feb.			74.9	79,088
Mar.			81.2	81,605
Apr.			78.8	83,970
May			56.6	85,724
June			53.7	87,335
July	9.56	3,142	50.3	88,894
Aug.	6.37	3,339	53.8	90,563
Sept.	4.09	3,462	61.3	92,402
Oct.	3.30	3,564	64.7	94,407
Nov.	3.17	3,659	66.3	96,395
Dec.	3.18	3,758	51.6	97,994
1934				
Jan.	2.89	3,847	40.0	99,235
Feb.	2.34	3,913	45.0	100,496
Mar.	2.47	3,990	44.5	101,874
Apr.	1.80	4,044	47.5	103,298
May	1.79	4,099	45.9	104,722
June	2.17	4,164	44.3	106,052

F-Unit

	Oil production		Water input	
Date	Daily	Cumulative	Daily	Cumulative
1930				
Feb.			25.5	713
Mar.			101.3	3,856
Apr.	.28	9	37.2	4,972
May	.29	18	19.8	5,585
June	.08	20	29.3	6,463
July	.04	21	30.7	7,414
Aug.	.13	25	78.2	9,838
Sept.	.12	29	57.7	11,570
Oct.	.10	32	40.6	12,829
Nov.	.14	36	16.6	13,327
Dec.	.17	41	32.8	14,344
1931				
Jan.	.11	45	36.2	15,465
Feb.			41.1	16,616
Mar.	.08	47	40.6	17,876
Apr.	.14	51	40.5	19,090
May	.17	57	40.7	20,352
June	.76	79	40.8	21,578
July	.50	95	41.9	22,876
Aug.	1.38	138	43.6	24,226
Sept.	2.08	200	46.8	25,630
Oct.	2.37	273	18.2	26,195
Nov.	2.58	351	38.6	27,353
Dec.	5.15	511	101.4	30.496
1932				
Jan.	5.37	677	82.7	33,061
Feb.	5.69	842	75.7	35,257
Mar.	6.20	1,035	72.3	37,497
Apr.	3.95	1,153	75.8	39,770
May	4.38	1,289	74.1	42,069
June	4.36	1,420	56.6	43,768
July	4.03	1,545	66.3	45,824
Aug.	3.35	1,654	62.0	47,747
Sept.	3.75	1,767	53.6	49,355
Oct.	3.82	1,885	50.2	50,913
Nov.	3.47	1,989	48.1	52,355
Dec.	3.06	2,084	45.1	53,753
1933				
Jan.	3.16	2,182	50.4	55,315
Feb.	3.29	2,274	51.0	56,744
Mar.	2.86	2,363	49.8	58,288
Apr.	2.86	2,449	50.2	59,793
May	2.83	2,537	43.8	61,150
June	3.08	2,629	47.3	62.571
July	3.10	2,725	52.8	64,209
Aug.	2.89	2,815	44.6	65,590
Sept.	2.35	2,885	44.1	66,914
Oct.	2.24	2,955	44.1	68,283
Nov.	1.79	3,009	39.3	69,461
Dec.	1.80	3,065	26.9	70,295
1934				
Jan.	2.19	3,132	20.8	70,941
Feb.	1.77	3,182	22.2	71,573
Mar.	1.88	3,240	22.3	72,264
Apr.	1.32	3,280	24.2	72,991
May	1.58	3,329	25.9	73,794
June	1.74	3,381	32.8	74,779

Flood No. 25

Flood No. 25 is a five-spot development started late in 1929 in the eastern part of the Knapp Creek dome gas cap. The distance between water intake wells is 316 feet and between water intake and oil wells, 224 feet. Water for flooding is obtained from the alluvium along the North Branch of Indian

Table 115. Total monthly and cumulative oil and water production of Flood No. 25, in barrels.

Date	Oil		Water	
	Monthly	Cumulative	Monthly	Cumulative
1929				
Dec.	289	289	253	253
1930				
Jan.	571	860	555	808
Feb.	749	1,608	694	1,502
Mar.	1,237	2,845	861	2,363
Apr.	1,617	4,462	566	2,929
May	1,912	6,374	621	3,550
June	1,749	8,124	533	4,083
July	1,624	9,748	527	4,610
Aug.	1,499	11,247	494	5,104
Sept.	1,544	12,791	518	5,621
Oct.	1,924	14,715	6.50	6,271
Nov.	1,693	16,408	670	6,942
Dec.	2,131	18,538	730	7,672
1931				
Jan.	2,165	20,704	828	8,500
Feb.	2,003	22,707	901	9,402
Mar.	2,212	24,919	1,044	10,446
Apr.	1,184	26,103	1,136	11,582
May	1 947	28,050	1,241	12,823
June	1,726	29,776	1,234	14,057
July	1,767	31,543	1,479	15,536
Aug.	1,666	33,210	1,699	17,235
Sept.	1,847	35,056	2,316	19,552
Oct.	1,934	36,990	2,901	22,453
Nov.	1,606	38,596	2,967	25,420
Dec.	1,445	40,041	3,111	28,531
1932				
Jan.	1,451	41,491	3,273	31,804
Feb.	1,233	42,724	3,150	34,954
Mar.	1,243	43,967	3,421	38,375
Apr.	1,159	45,127	3,408	41,783
May	1,120	46,246	3,482	45,265
June	1,103	47,350	3,666	48,931
July	1,047	48,396	3,727	52,658
Aug.	1,012	49,408	3,881	56,539
Sept.	946	50,354	3,936	60,475
Oct.	929	51,284	4,117	64,592
Nov.	846	52,130	4,125	68,717
Dec.	843	52,973	4,393	73,111
1933				
Jan.	799	53,773	4,373	77,484
Feb.	697	54,470	4,048	81,532
Mar.	747	55,216	4,530	86,062
Apr.	679	55,845	4,329	90,392
May	693	56,588	4,471	94,863
June	641	57,229	2,317	97,180
July	639	57,868		
Aug.	612	58,480		
Sept.	561	59,041		
Oct.	548	59,589		
Nov.	507	60,096		
Dec.	506	60,601		
1934				
Jan.	492	61,094		
Feb.	424	61,518		
Mar.	444	61,962		
Apr.	412	62,374		
May	412	62,786		
June	381	63,167		
July	396	63,563		
Aug.	382	63,945		
Sept.	360	64,305		
Oct.	353	64,658		
Nov.	356	65,014		
Dec.	339	65,353		
1935				
Jan.	317	65,670		
Feb.	257	65,927		
Mar.	335	66,262		

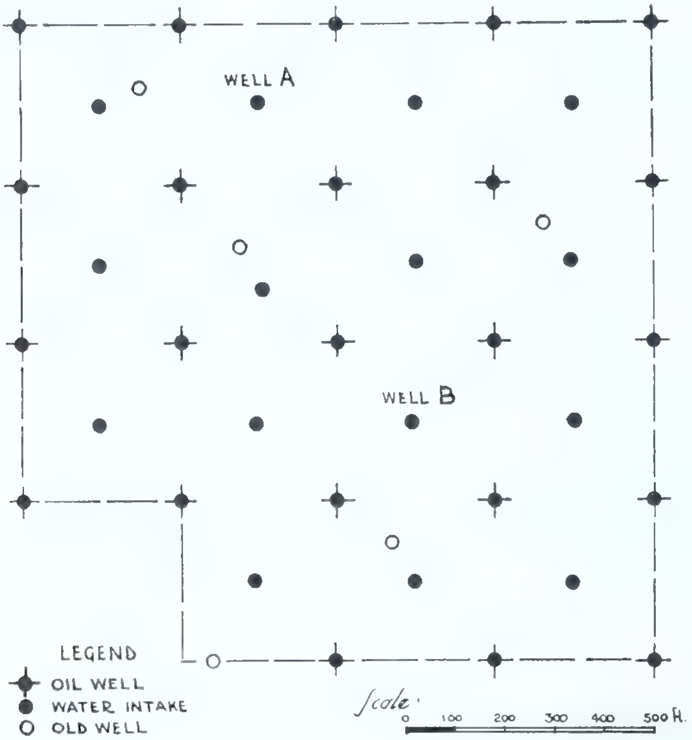


FIGURE 90. Map of Flood No. 25.

Creek. It is not filtered. The water-pumping plant was put in operation in December 1929. At first the water was introduced into the intake wells at a pressure equivalent to 900 pounds per square inch at the face of the sand. By the end of March 1930 this had been raised to 1,550 pounds. In order to curtail production, it was reduced during May 1930 and by July 7 was again down to 900 pounds. It was then raised to 1,550 pounds at the end of September 1930, and has been maintained there.

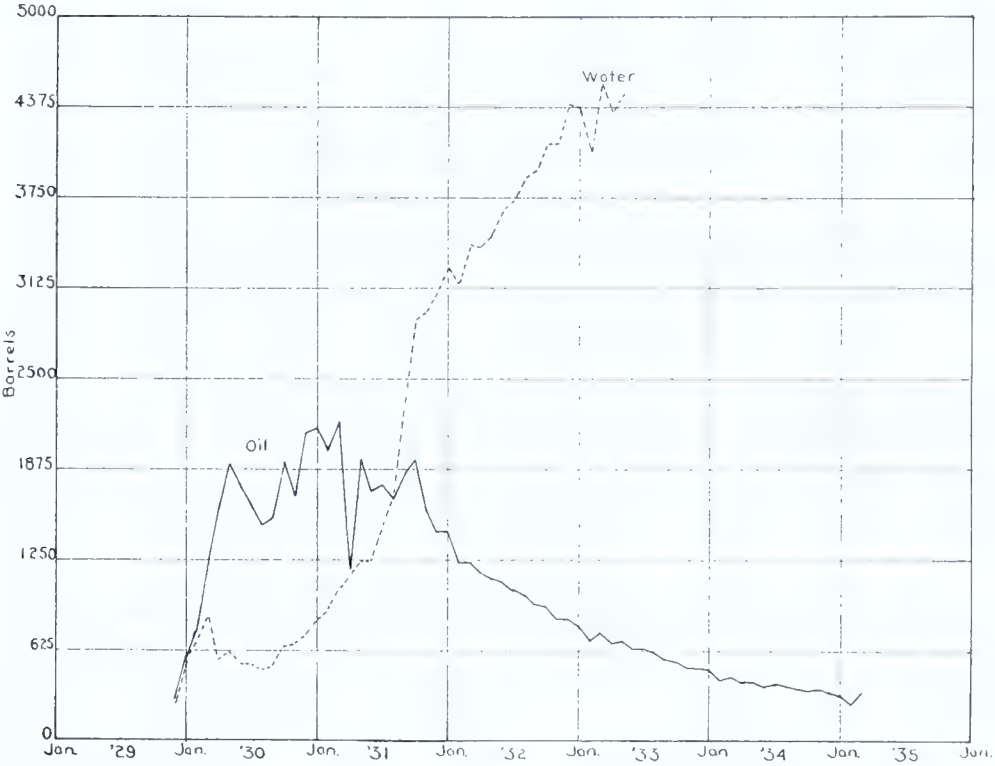


FIGURE 91. Curves showing total monthly oil and water production of Flood No. 25.

The area shown in Figure 90 represents 34.5 acres. From it 66,262 barrels of oil had been recovered by the end of March 1935, an average yield of 1,921 barrels per acre. According to the drillers' records, the sand has an average thickness of 74 feet, of which 21 feet is gas pay and 43 feet is oil pay. It is estimated that 73 percent or 31 feet of the oil pay is oil-bearing sandstone. The yield per acre-foot during the above period, therefore, was 62 barrels. The average daily oil production per well during March 1935 was still 0.72

barrels. The above figures will, therefore, be increased slightly before the economic limit is reached. At the end of June 16, 1933 the tract had produced 56,938 barrels of oil and 97,180 barrels of water, giving a water output to oil ratio for this period of 1.71:1. By that time the water production had become so large that it was no longer feasible to keep a daily gauge. The total monthly and cumulative oil and water production of Flood No. 25 are given in Table 115 and are shown graphically in Figure 91.

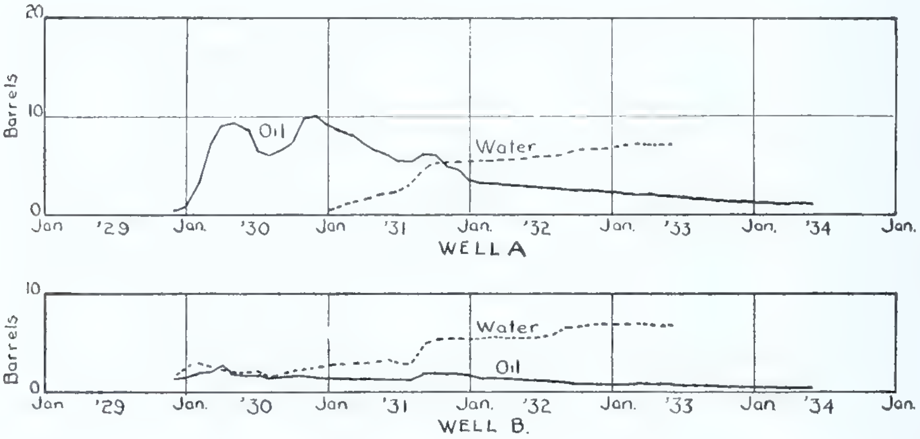


FIGURE 92. **Curves showing average daily oil and water production by months of wells A and B in Flood No. 25.**

The relation of the fluid output to input for Flood No. 25 during April 1930 and May 1933 is given in Table 116. This is based upon the assumption that the water introduced into each intake well of a five-spot unit is equally distributed in the four quadrants about the well. In Flood No. 25, 64 percent of the water introduced was assigned to the tract under discussion. It will be noted that after nearly 3½ years of operation, large volumes of water were still being introduced in the intake wells that were not accounted for in the fluid output.

Table 116. Relation of fluid output to input for Flood No. 25 in barrels.

Date	Oil production	Water output	Total fluid output	Water input
April 1930	1,617	566	2,183	22,050
May 1933	693	4,471	5,164	11,880

The average daily and cumulative oil and water production by months of wells A and B in Flood No. 25 are given in Table 117 and are shown graphically in Figure 92.

Table 117. Average daily and cumulative oil and water production by months of wells A and B in Flood No. 25, in barrels.

	Well A					**Well B**			
	Oil		Water			Oil		Water	
Date	Daily	Cumulative	Daily	Cumulative	Date	Daily	Cumulative	Daily	Cumulative
1929					1929				
Dec.	.41	13			Dec.	1.50	27	1.84	33
1930					1930				
Jan.	.99	43			Jan.	1.73	81	2.57	113
Feb.	3.22	137	.05	1	Feb.	1.98	136	3.00	197
Mar.	7.17	356	.05	3	Mar.	2.13	202	2.55	276
Apr.	9.09	628			Apr.	2.65	282	2.29	345
May	9.52	924			May	1.85	339	1.89	404
June	8.41	1,176			June	1.72	391	1.81	458
July	6.58	1,380			July	1.81	447	2.00	520
Aug.	6.15	1,571			Aug.	1.54	494	1.76	575
Sept.	6.62	1,769			Sept.	1.61	543	1.76	628
Oct.	8.55	2,035			Oct.	1.72	596	2.19	696
Nov.	9.95	2,333			Nov.	1.74	648	2.32	765
Dec.	10.00	2,643			Dec.	1.54	696	2.53	844
1931					1931				
Jan.	9.03	2,923	.53	19	Jan.	1.40	739	2.68	927
Feb.	8.59	3,164	.96	46	Feb.	1.35	777	2.84	1,006
Mar.	8.25	3,419	1.34	88	Mar.	1.36	819	2.93	1,097
Apr.	7.22	3,636	1.77	141	Apr.	1.39	861	2.97	1,186
May	6.54	3,838	1.96	201	May	1.37	903	3.01	1,279
June	6.15	4,023	2.15	266	June	1.34	943	3.28	1,378
July	5.79	4,202	2.49	343	July	1.35	985	2.88	1,467
Aug.	5.64	4,377	3.13	440	Aug.	1.39	1,028	2.89	1,557
Sept.	6.13	4,561	4.49	575	Sept.	1.90	1,085	4.73	1,698
Oct.	6.08	4,749	5.40	742	Oct.	1.84	1,142	5.32	1,863
Nov.	4.93	4,897	5.45	906	Nov.	1.81	1,197	5.51	2,028
Dec.	4.49	5,037	5.45	1,075	Dec.	1.73	1,251	5.49	2,198
1932					1932				
Jan.	3.62	5,149	5.68	1,251	Jan.	1.68	1,303	5.49	2,369
Feb.	3.39	5,247	5.67	1,416	Feb.	1.45	1,345	5.44	2,526
Mar.	3.24	5,348	5.75	1,594	Mar.	1.46	1,390	5.80	2,705
Apr.	3.12	5,441	5.80	1,768	Apr.	1.33	1,430	5.67	2,875
May	2.96	5,533	5.87	1,950	May	1.38	1,474	5.72	3,053
June	2.80	5,617	5.94	2,128	June	1.21	1,510	5.74	3,225
July	2.68	5,700	6.02	2,315	July	1.12	1,545	5.87	3,407
Aug.	2.57	5,780	6.23	2,508	Aug.	1.09	1,579	5.96	3,592
Sept.	2.51	5,855	6.49	2,703	Sept.	.99	1,608	6.45	3,785
Oct.	2.41	5,930	6.59	2,907	Oct	.93	1,637	6.51	3,987
Nov.	2.31	5,999	6.76	3,110	Nov.	.85	1,664	6.79	4,191
Dec.	2.25	6,069	6.93	3,325	Dec.	.87	1,691	6.93	4,405
1933					1933				
Jan.	2.16	6,136	6.88	3,538	Jan.	.82	1,716	6.84	4,617
Feb.	2.07	6,194	7.06	3,735	Feb	.78	1,738	6.94	4,812
Mar.	2.05	6,258	7.16	3,957	Mar.	.74	1,761	6.98	5,028
Apr.	1.95	6,316	7.11	4,171	Apr.	.70	1,782	6.87	5,234
May	1.90	6,375	7.12	4,391	May	.66	1,803	6.85	5,446
June	1.82	6,430	7.14	4,506	June	.65	1,822	6.82	5,556
July	1.79	6,485			July	.61	1,841		
Aug.	1.74	6,539			Aug.	.55	1,858		
Sept.	1.66	6,589			Sept.	.57	1,875		
Oct.	1.58	6,638			Oct.	.51	1,891		
Nov.	1.51	6,683			Nov.	.47	1,905		
Dec.	1.43	6,728			Dec.	.43	1,919		
1934					1934				
Jan.	1.42	6,772			Jan.	.36	1,930		
Feb.	1.33	6,809			Feb.	.39	1,941		
Mar.	1.24	6,848			Mar.	.39	1,953		
Apr.	1.20	6,884			Apr.	.35	1,963		
May	1.16	6,920			May	.36	1,974		
June	1.14	6,937			June	.34	1,980		

Flood No. 26

Flood No. 26 is along the eastern margin of the Rixford dome gas cap south of Rixford. The portion of the flood whose production is discussed comprises 26.26 acres, and is shown in Figure 93. The distance between water intake wells, except where it was necessary to adjust the pattern to property lines, is 283 feet in one direction and 263 feet in the other, making the distance between water intake and oil wells 193 feet. Water for flooding is obtained from the alluvium along the South Branch of Knapp Creek below Rixford. It is not filtered. Although the intake wells were drilled during 1930-1932, water was not introduced until August 1, 1933. The pressure employed is equivalent to about 800 pounds per square inch at the face of the sand.

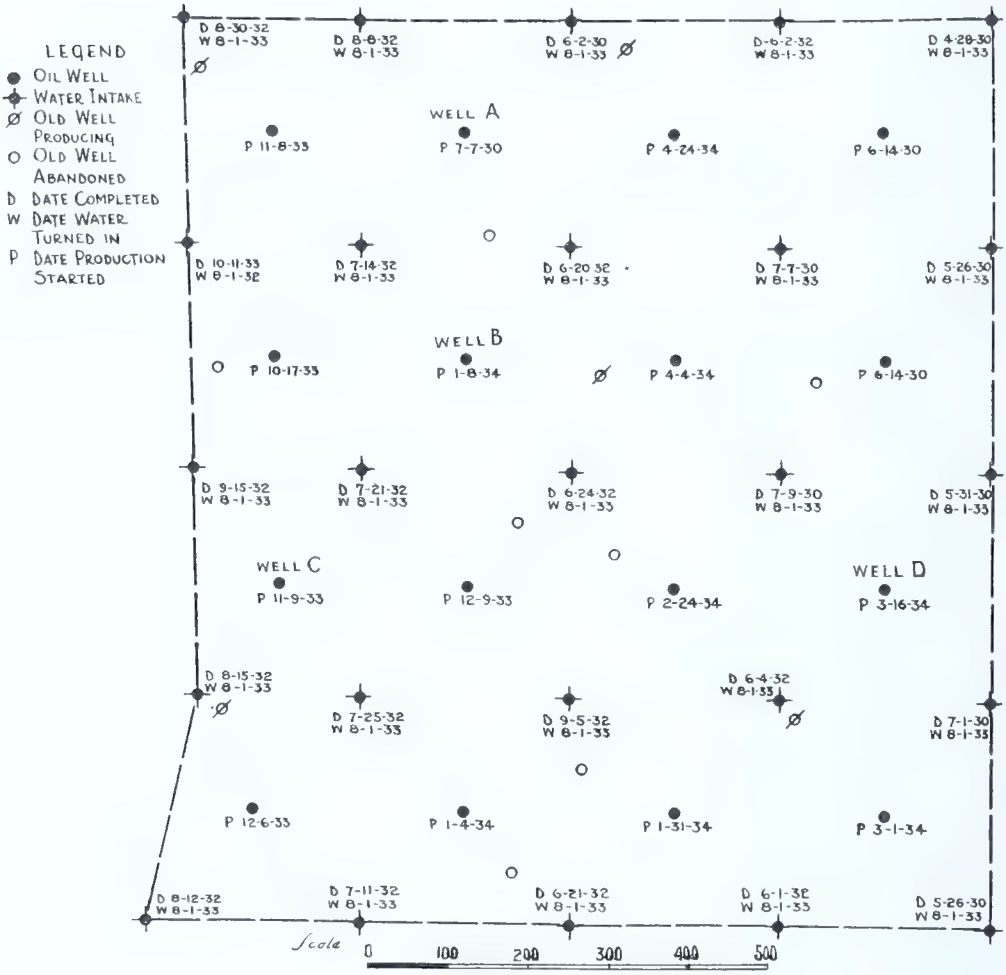


FIGURE 93. **Map of Flood No. 26.**

Table 118. Total monthly and cumulative oil production of Flood No. 26, in barrels.

Date	Monthly	Cumulative	Date	Monthly	Cumulative
1933			1934		
July	514	514	Aug.	5,225	88,488
Aug.	5,309	5,823	Sept.	4,471	92,959
Sept.	5,136	10,959	Oct.	3,867	96,826
Oct.	7,484	18,443	Nov.	3,429	100,255
Nov.	8,583	27,026	Dec.	3,507	103,762
Dec.	8,462	35,488	1935		
1934			Jan.	2,696	106,458
Jan.	8,087	43,575	Feb.	2,534	108,992
Feb.	6,481	50,055	Mar.	2,683	111,676
Mar.	6,492	56,547	Apr.	2,469	114,144
Apr.	6,928	63,475	May	2,410	116,554
May	7,301	70,776	June	2,230	118,784
June	6,416	77,192	July	2,173	120,957
July	6,070	83,263	Aug.	1,915	122,872

At the end of August 1935, the total oil recovery from the 26.26 acres had reached 122,872 barrels, an average yield of 4,679 barrels per acre. According to the drillers' records, the sand body has an average thickness of 44 feet. It is estimated that 75 percent or 35 feet of this oil-bearing sand-

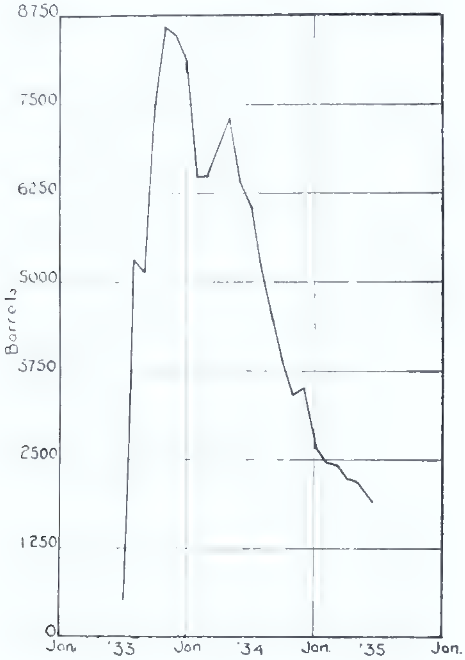


FIGURE 94. Curve showing total monthly oil production of Flood No. 26.

Table 119. Average daily and cumulative oil production of four wells in Flood No. 26 by months, in barrels.

	Well A		**Well B**		**Well C**		**Well D**	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative
1933								
July	**2.80**	**25**						
Aug.	**12.32**	**407**						
Sept.	**23.98**	**1,127**						
Oct.	**21.18**	**1,783**						
Nov.	**17.77**	**2,317**			102.62	2,668		
Dec.	**19.00**	**2,905**			55.80	4,399		
1934								
Jan.	**16.31**	**3,411**	41.63	1,041	27.37	5,247		
Feb.	**16.16**	**3,864**	31.30	1,917	18.50	5,765		
Mar.	15.18	4,334	23.68	2,651	16.55	6,279	8.43	177
Apr.	16.12	4,818	21.14	3,285	14.50	6,713	10.11	480
May	14.87	5,279	18.92	3,872	14.37	7,159	8.48	743
June	13.73	5,692	16.74	4,374	12.66	7,539	6.72	945
July	14.26	6,134	15.68	4,860	11.71	7,902	6.42	1,144
Aug.	12.22	6,512	13.56	5,280	9.98	8,211	5.67	1,320
Sept.	12.30	6,881	12.40	5,652	8.73	8,473	4.34	1,450
Oct.	11.08	7,225	9.96	5,961	7.72	8,712	4.13	1,578
Nov.	8.55	7,481	9.48	6,246	7.28	8,931	3.84	1,693
Dec.	9.87	7,787	7.07	6,527	6.87	9,144	4.02	1,818
1935								
Jan.	7.72	8,027	6.91	6,741	5.37	9,310	2.95	1,909
Feb.	7.37	8,233	7.56	6,952	5.69	9,467	3.21	1,999
Mar.	5.93	8,417	7.34	7,180	5.46	9,636	3.17	2,097
Apr.	6.55	8,613	7.07	7,392	5.52	9,802	3.05	2,189
May	5.98	8,799	6.64	7,598	5.28	9,965	2.88	2,278
June	5.63	8,968	6.20	7,784	5.12	10,119	2.76	2,361
July	5.24	9,130	5.72	7,961	4.92	10,271	2.61	2,442
Aug.	5.07	9,287	5.53	8,133	4.82	10,421	2.57	2,531

stone. The yield per acre-foot during the above period, therefore, was 142 barrels. At the end of August 1935, the average daily oil production per well of the 16 new wells was still 3.86 barrels and of four old wells, 1.73 barrels. The above figures will, therefore, be increased somewhat before the economic limit is reached. The total monthly and cumulative oil production of the tract are given in Table 118 and the former is shown graphically in Figure 94.

The average daily and cumulative oil production of four wells in Flood No. 26 by months are given in Table 119 and are shown graphically in Figure 95. A considerable difference in yield occurs between individual wells. This is illustrated by wells C and D which are only 760 feet apart. Although well

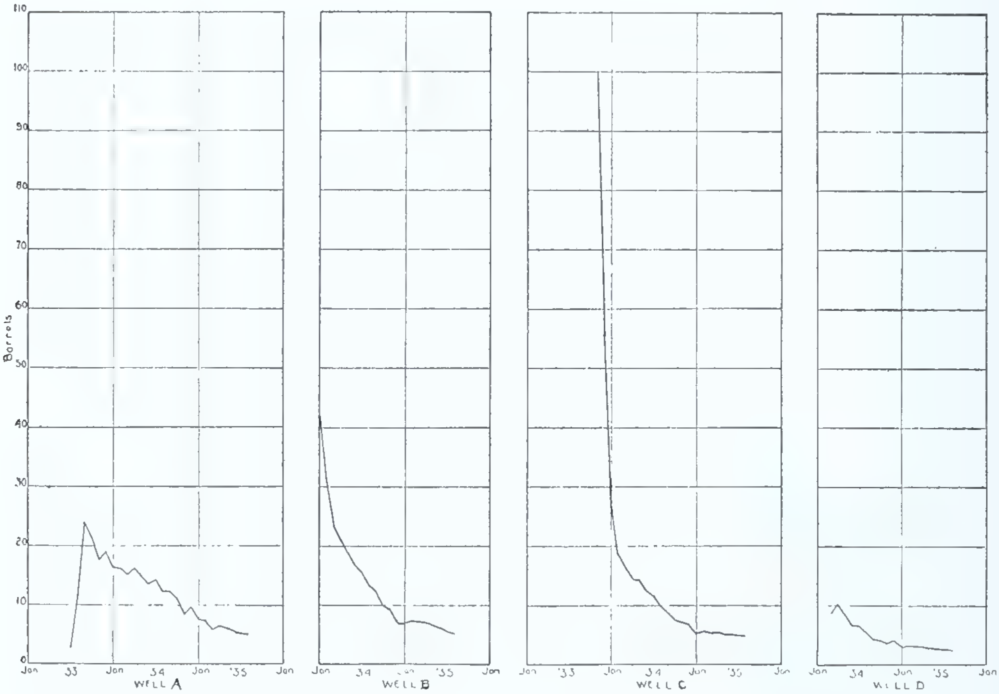


FIGURE 95. Curves showing average daily oil production by months of four wells in Flood No. 26.

Table 120. Screen analyses, average grain diameter, porosity and permeability of two samples of Bradford Third sand from Flood No. 26.

Size of openings Millimeters Through	Caught On	Sample No. 1 Percent	Sample No. 2 Percent
.589	.417	0.0	0.0
.417	.295	0.0	0.0
.295	.208	0.2	0.3
.208	.147	37.0	33.7
.147	.104	43.3	47.1
.104	.074	10.4	10.8
.074	.061	3.2	3.3
.061	.043	1.6	1.4
.043		4.3	3.4
Average grain diameter—mm.		.128	.138
Porosity percent		23.8	25.8
Permeability—millidarcys		227.97	209.13

C drains an area only three-fourths the size of that drained by well D, it has produced four times as much oil.

Flood No. 26 is along a narrow belt of relatively permeable sand on the eastern margin of the Rixford dome gas cap. Some of the early wells drilled in this area during 1878-79 had initial production of 150 to 400 barrels per day. Screen analyses and porosity and permeability determinations were made on two large fragments of Bradford Third sand recovered after a shot from one of the wells in Flood No. 26. The results are given in Table 120. The average grain diameter, porosity, and permeability are considerably higher than the average for the Bradford pool as a whole.

Water was first admitted to the intake wells on August 1, 1933. Although the distance between intake and producing wells is 193 feet, the production of the output wells showed a marked increase almost immediately. Large volumes of water have accompanied the oil almost from the start so that it has been necessary to pump the producing wells continuously. Some wells reached a peak in excess of 100 barrels of oil per day, but their decline has been relatively rapid.

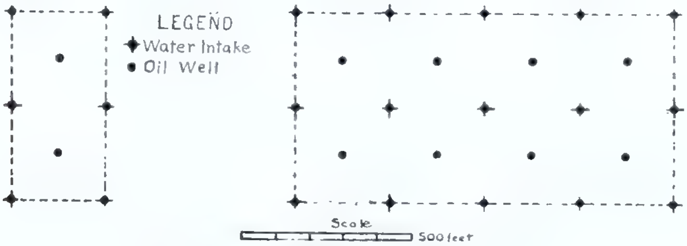


FIGURE 96. **Map of Flood No. 27.**

Flood No .27

Flood No. 27 is a five-spot development of 10 units of 1.8 acres each at the head of Harrisburg Run in a marginal portion of the Bradford pool. An attempt has been made to flood the Harrisburg Run and Bradford Third sands simultaneously on this property. The average interval between the tops of the two sands is 259 feet. According to the drillers' records, the Harrisburg Run sand has an average thickness of 25 feet and the Bradford Third sand, 28 feet. What proportion of these thicknesses is oil-bearing sandstone is not known. The distance between water intake wells is 280 feet and between water intake and oil wells, 198 feet. Water for flooding is obtained from wells sunk in the alluvium near the head of Harrisburg Run. It is not filtered. The pump pressure at the water plant had been maintained at such a level as to give about 1,700 pounds per square inch at the face of the Bradford Third sand in the intake wells.

From November 1930 to the end of February 1934, 29,160 barrels of oil were recovered from the 18 acres shown in Figure 96, or an average of 1,620 barrels per acre. The total monthly and the cumulative oil and water production are given in Table 121. The former is shown graphically in Figure 97. During February 1934 the average daily oil production per well was still 1.43 barrels. The above yield per acre will, therefore, be increased somewhat before the economic limit is reached. At the end of October 1932, the total oil and water output had reached 20,804 and 141,685 barrels, respectively, giving a water output to oil ratio of 6.81:1 for this period. During October 1932, the water output to oil ratio was 11.67:1. The water output has not been gauged since November 5, 1932.

During the four-week period ending November 5, the water input for the wells shown in Figure 96 was 21,765 barrels. On the assumption that the water was equally distributed in the four quadrants about each intake well, 48 percent or 10,477 barrels of this can be assigned to the ten producing units. Since the adjacent units have not been developed, this estimate probably is low. During the same period, 592 barrels of oil and 6,905 barrels of water or a total of 7,497 barrels of fluid were recovered from the ten producing wells.

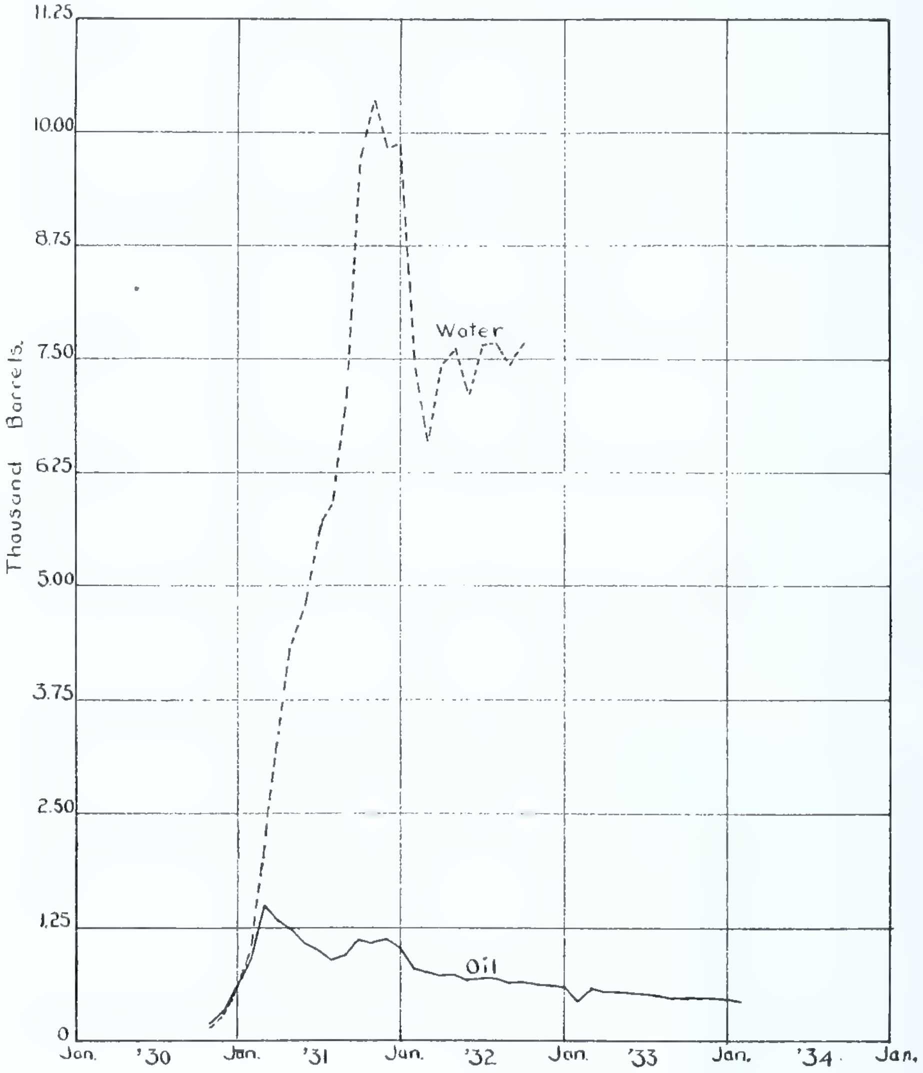


FIGURE 97. Curves showing total monthly oil and water production of Flood No. 27.

Table 121. Total monthly and cumulative oil and water production of Flood No. 27, in barrels.

	Oil		Water	
Date	Monthly	Cumulative	Monthly	Cumulative
1930				
Nov.	203	203	184	184
Dec.	330	534	249	433
1931				
Jan.	621	1,155	587	1,020
Feb.	905	2,059	996	2,016
Mar.	1,491	3,550	2,206	4,223
Apr.	1,336	4,886	3,333	7,556
May	1,250	6,136	4,345	12,901
June	1,073	7,208	4,798	16,699
July	1,000	8,208	5,657	22,356
Aug.	902	9,110	5,931	28,287
Sept.	946	10,056	7,030	35,316
Oct.	1,129	11,186	9,706	45,023
Nov.	1,086	12,271	10,374	55,396
Dec.	1,123	13,395	9,825	65,222
1932				
Jan.	1,021	14,416	9,884	75,106
Feb.	792	15,208	7,408	82,514
Mar.	760	15,968	6,560	89,074
Apr.	723	16,691	7,452	96,526
May	732	17,423	7,620	104,147
June	688	18,111	7,107	111,255
1932				
July	699	18,810	7,649	118,903
Aug.	690	19,501	7,684	126,588
Sept.	647	20,184	7,439	134,026
Oct.	656	20,804	7,658	141,685
Nov.	622	21,426		
Dec.	624	22,050		
1933				
Jan.	611	22,661		
Feb.	438	23,099		
Mar.	582	23,619		
Apr.	551	24,233		
May	552	24,785		
June	526	25,311		
July	527	25,837		
Aug.	517	26,354		
Sept.	489	26,843		
Oct.	483	27,326		
Nov.	476	27,802		
Dec.	487	28,289		
1934				
Jan.	471	28,760		
Feb.	400	29,160		

Intensive Water-floods outside Bradford District

The Bradford Third sand has proven amenable to water flooding in at least two pools outside the Bradford district, namely, the Richburg pool in Allegany County, New York and the Burning Well pool in Sergeant and Wetmore Townships in the southern part of McKean County, Pennsylvania. Studies made of cores taken in these two pools have shown 'that the sand is very similar in mineralogical composition, grain size, porosity, permeability and degree of oil saturation to its development in the Bradford pool.

RICHBURG POOL, NEW YORK

Water flooding has been practiced in the Richburg pool of Allegany County, New York almost as long as in the Bradford district and with equally satisfactory results. The application of hydraulic pressure to that of the hydrostatic head of the column of water in the intake wells by introducing the water under pressure at the top of the well was first done on a large scale in this pool.

Flood No. 28

Flood No. 28, the first five-spot operation in which water was introduced under pressure at the top of the intake wells, is in the center of the Richburg pool, east of Bolivar, Allegany County, New York. A tract of 72 acres, shown in Figure 98, is developed by 54 water intake wells and 40 oil wells. The distance between water intake wells is 280 feet and between water intake and oil wells 198 feet. The intake wells were completed between November 28, 1927, and March 12, 1928, and the oil wells from February 14 to May 14, 1928. Production commenced July 1, 1928. Starting August 4 with a pressure equivalent to 540 pounds per square inch at the face of the sand in the intake wells, this was gradually raised until on July 6, 1929, it reached 1,200 pounds. In order to curtail production during the period of proration, the pressure was reduced to 550 pounds from May 1930 to June 1931. Since that time it has been maintained at 1,050 pounds. Water is obtained from a single well capable of producing 4,000 barrels per day, in the alluvium of the main valley at the south end of the property. An air-lift raises the water. It is not filtered. During dry months, the water-table is lowered 50 feet.

From July 1928 to the end of March 1935, the tract yielded 433,476 barrels of oil, or an average of 6,020 barrels per acre. According to the drillers' records, the sand body ranges in thickness from 14 to 64 feet, the average being 31 feet. As no cores were taken, the thickness of oil-bearing sandstone is not known. The total monthly oil and water production are given in Table 122. The former, as well as the pressure in pounds per square inch at the face of the sand in the intake wells and the average daily water input per intake well, are shown graphically in Figure 99. By March 1935 the average daily oil production per well had dropped to 0.65 barrels. The operation has, therefore, almost reached its economic limit. The oil production for each year and the percent this is of the total for the entire period are given in Table 123. It will be noted that 73.5 percent of the amount was recovered during the first two years and 83.5 percent during the first three years. Measurement of the water output was stopped at the end of October 1931. During the last

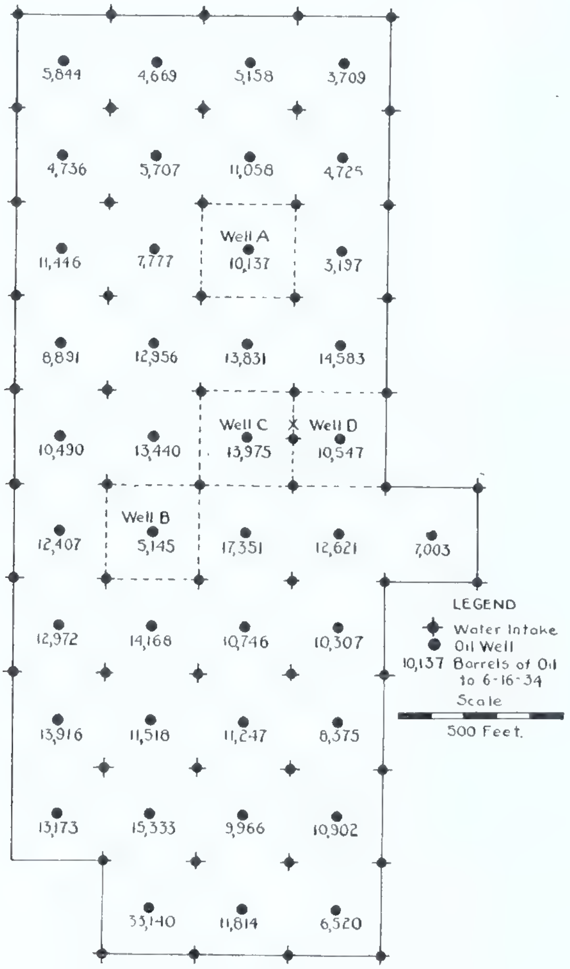


FIGURE 98. Map of Flood No. 28.

month that measurements were made, the water output to oil ratio was 8:1. Up to the end of October 1931 it was 1.15:1. In that interval 87 percent of the oil produced to the end of March 1935 had been recovered.

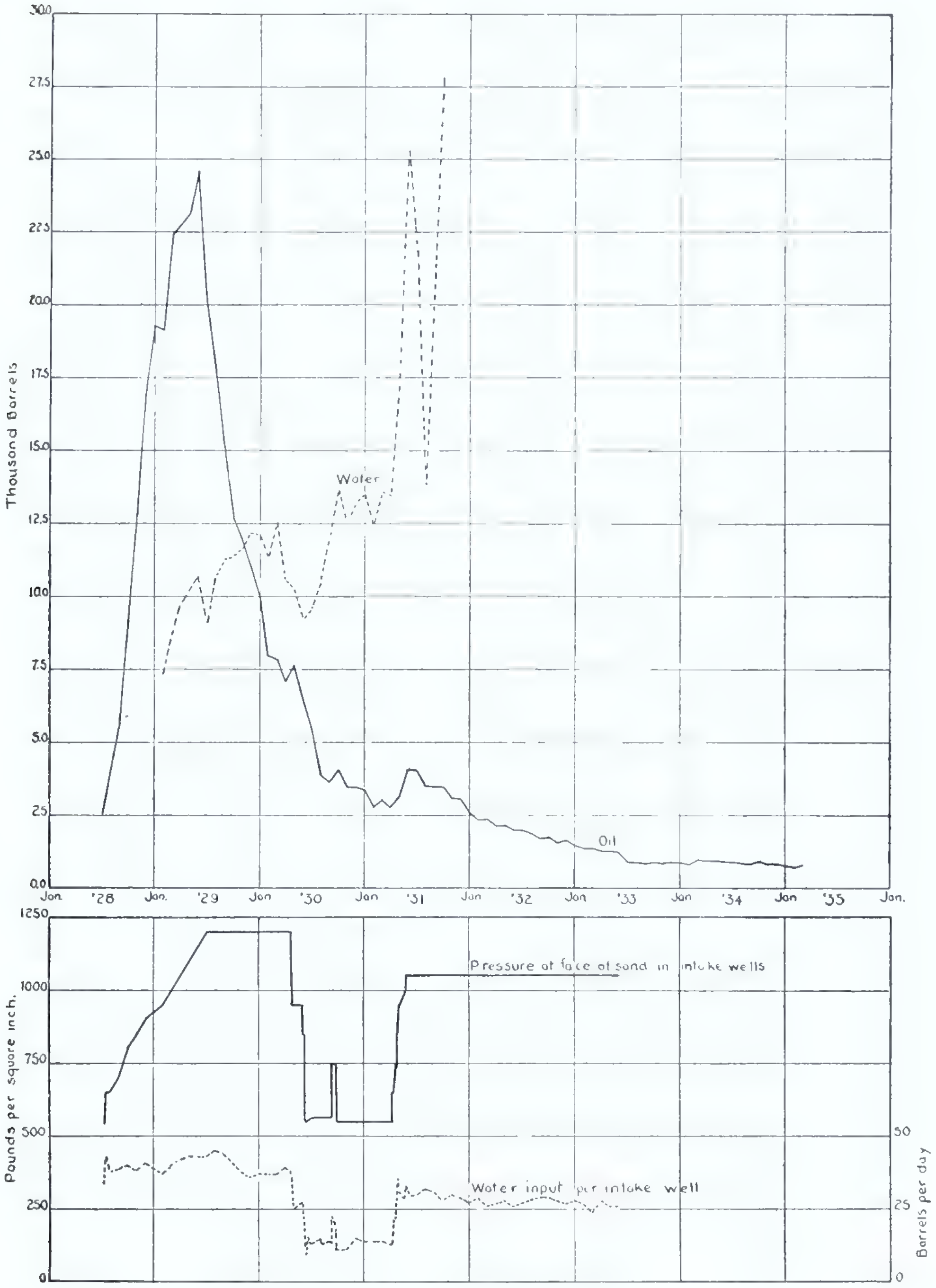


Figure 99. Curves showing total monthly oil and water production, pressure in pounds per square inch at face of sand in intake wells, and average daily water input per intake well of Flood No. 28.

Table 122. Total monthly and cumulative oil and water production of Flood No. 28, in barrels.

	Oil		Water	
Date	Monthly	Cumulative	Monthly	Cumulative
1928				
July	2,576	2,576		
Aug.	3,987	6,563		
Sept.	5,672	12,235		
Oct.	9,272	21,507		
Nov.	12,751	34,258		
Dec.	16,870	51,128		
1929				
Jan.	19,277	70,405		
Feb.	19,125	89,530	7,314	7,314
Mar.	22,406	111,936	8,693	16,007
Apr.	22,772	134,708	9,743	25,750
May	23,169	157,877	10,160	35,910
June	24,613	182,490	10,739	46,649
July	19,993	202,483	9,073	55,686
Aug.	17,954	220,437	10,681	66,367
Sept.	15,235	235,672	11,272	77,639
Oct.	12,699	248,371	11,373	89,012
Nov.	11,985	260,356	11,608	100,620
Dec.	11,093	271,449	12,162	112,782
1930				
Jan.	10,045	281,494	12,117	124,899
Feb.	7,961	289,455	11,318	136,217
Mar.	7,864	297,319	12,557	148,774
Apr.	7,103	304,422	10,547	159,321
May	7,632	312,054	10,309	169,630
June	6,548	318,602	9,207	178,837
July	5,447	324,049	9,608	188,445
Aug.	3,889	327,938	10,530	198,975
Sept.	3,659	331,597	12,032	211,007
Oct.	4,042	335,639	13,667	224,674
Nov.	3,483	339,122	12,565	237,239
Dec.	3,481	342,603	13,228	250,467
1931				
Jan.	3,397	346,000	13,518	263,985
Feb.	2,801	348,801	12,439	276,424
Mar.	3,025	351,826	13,571	289,995
Apr.	2,792	354,618	13,472	303,467
May	3,177	357,795	17,420	320,887
June	4,069	361,864	25,351	346,238
July	4,062	365,926	21,957	368,195
Aug.	3,509	369,435	13,873	382,068
Sept.	3,471	372,906	21,501	403,569
Oct.	3,488	376,394	27,828	431,397
1931				
Nov.	3,082	379,476		
Dec.	3,071	382,547		
1932				
Jan.	2,588	385,135		
Feb.	2,341	387,476		
Mar.	2,372	389,848		
Apr.	2,194	392,042		
May	2,178	394,220		
June	2,025	396,245		
July	2,005	398,250		
Aug.	1,898	400,148		
Sept.	1,731	401,879		
Oct.	1,743	403,622		
Nov.	1,578	405,200		
Dec.	1,659	406,859		
1933				
Jan.	1,479	408,338		
Feb.	1,398	409,736		
Mar.	1,399	411,135		
Apr.	1,315	412,450		
May	1,313	413,763		
June	1,256	415,019		
July	911	415,930		
Aug.	911	416,841		
Sept.	881	417,722		
Oct.	911	418,633		
Nov.	881	419,514		
Dec.	911	420,425		
1934				
Jan.	911	421,336		
Feb.	823	422,159		
Mar.	975	423,134		
Apr.	938	424,072		
May	951	425,023		
June	897	425,920		
July	893	426,813		
Aug.	861	427,674		
Sept.	838	428,512		
Oct.	930	429,442		
Nov.	858	430,300		
Dec.	845	431,145		
1935				
Jan.	795	431,940		
Feb.	728	432,668		
Mar.	808	433,476		

The average daily and the cumulative oil and water production of wells A and B and of wells C and D are given in Tables 124 and 125, respectively. Curves for the average daily production are shown in Figures 100 and 101. Well A is about an average well, and B is considerably below average. Wells

Table 123. Oil production by years of Flood No. 28 and percent of production for entire period.

Year	Oil production, barrels	Percent
1st	182,490	42.1
2nd	136,112	31.4
3rd	43,262	10.0
4th	34,381	7.9
5th	18,774	4.3
6th	10,901	2.5
Last 9 months	7,556	1.8

C and D are adjacent wells that exhibited a unique behaviour. Wells A and B started producing in July 1928. B reached its peak in January and A, May 1929. The peak for the entire tract was reached June 1929. Wells C and D started producing in September 1928, only two months later than A and B. As late as March 1930 these two wells seemed to be failures although there were good producers on at least three sides. An additional water intake was, therefore, completed midway between them on March 26, 1930. Its location is shown by the X in Figure 98. The two wells responded almost immediately, both reaching peaks in June 1931. Well C finally had a total production considerably above that of the average well on the tract and well D, equivalent to that of the average well. Apparently wells C and D intersected a lens of oil-bearing sandstone that was not adequately supplied with water from the intake wells of the regular pattern. When the intake well drilled midway between them admitted water to this lens, they responded almost immediately.

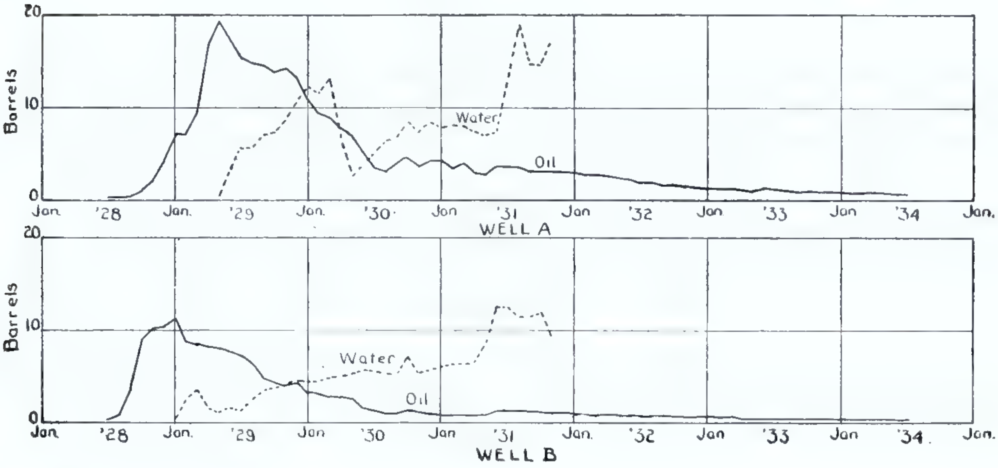


FIGURE 100. **Curves showing average daily oil and water production by months of wells A and B in Flood No. 28.**

It is irregularities of this type in the sand body that necessitate the relatively close spacing used in both the Bradford and Richburg pools in order to obtain a maximum recovery of oil.

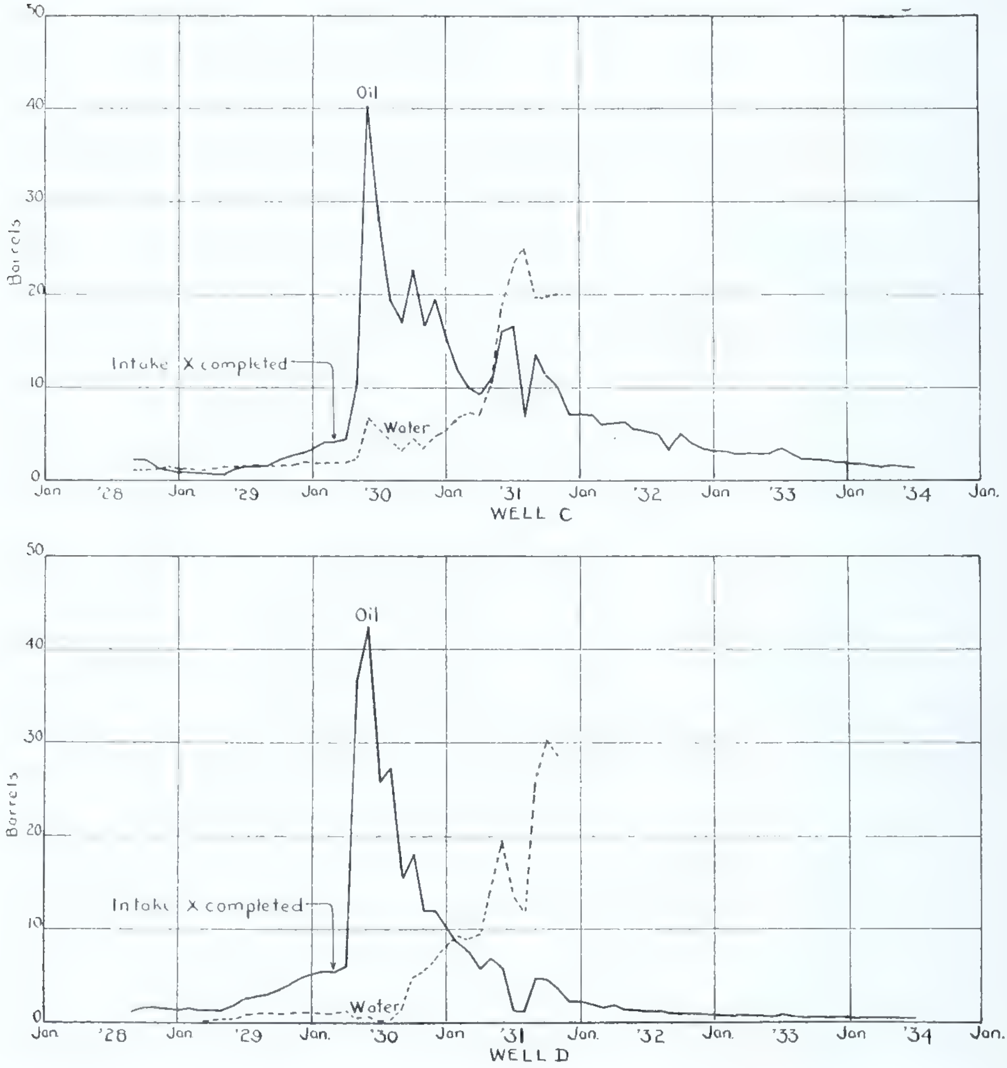


FIGURE 101. **Curves showing average daily oil and water production by months of wells C and D in Flood No. 28.**

BURNING WELL POOL, McKEAN COUNTY

The Burning Well pool is in Sergeant and Wetmore Townships in the southern part of McKean County, Pennsylvania. Oil is obtained from the Bradford Third sand. The Kane sand yields gas only. Wilson K. Page of Olean, New York, has demonstrated that portions at least of this pool are amendable to water-flooding and that results comparable to those in the Bradford district can be obtained. Extensive flooding was first undertaken in 1929.

Table 124. Average daily and cumulative oil and water production by months of wells A and B in Flood No. 28, in barrels.

Well A					**Well B**				
	Oil		Water			Oil		Water	
Date	Daily	Cumulative	Daily	Cumulative	Date	Daily	Cumulative	Daily	Cumulative
1928									
July	.36	10	.01		July	.24	7	.05	1
Aug.	.28	19			Aug.	.71	31	.02	2
Sept.	.49	34			Sept.	3.87	137	.02	3
Oct.	1.17	70			Oct.	9.19	410		3
Nov.	2.10	133			Nov.	10.15	714		3
Dec.	4.24	264			Dec.	10.34	1,036		3
1929									
Jan.	7.41	494			Jan.	11.18	1,378	.47	17
Feb.	7.57	705	.18	5	Feb.	8.78	1,625	2.55	95
Mar.	9.64	1,004			Mar.	8.40	1,884	3.71	206
Apr.	16.96	1,512			Apr.	8.10	2,128	1.63	255
May	19.55	2,118	.23	12	May	8.02	2,377	.93	283
June	17.44	2,641	3.52	118	June	7.68	2,607	1.73	318
July	15.47	3,120	5.83	298	July	7.31	2,834	1.46	411
Aug.	14.82	3,580	5.94	483	Aug.	6.28	3,029	2.29	526
Sept.	14.66	4.019	6.95	691	Sept.	4.68	3,169	3.62	634
Oct.	13.95	4,452	7.27	917	Oct.	4.32	3,304	3.84	754
Nov.	14.27	4,880	8.88	1,183	Nov.	4.05	3,426	4.07	876
Dec.	13.51	5.299	10.79	1,518	Dec.	4.32	3,538	4.49	1,009
1930									
Jan.	10.94	5,638	12.33	1,900	Jan.	3.38	3,623	4.42	1,147
Feb.	9.43	5,905	11.84	2,232	Feb.	3.12	3,707	4.56	1,275
Mar.	8.90	6,181	13.34	2,646	Mar.	2.87	3,796	4.93	1,427
Apr.	7.71	6,412	6.31	2,835	Apr.	2.74	3,879	5.06	1,590
May	6.99	6,629	2.52	2,913	May	2.46	3,955	5.24	1,752
June	5.29	6,788	3.91	3,031	June	1.76	4,008	5.80	1,926
July	3.74	6,904	5.18	3,191	July	1.35	4,050	5.67	2,091
Aug.	3.22	7,005	6.34	3,388	Aug.	1.03	4,082	5.21	2,254
Sept.	4.03	7,126	6.86	3,594	Sept.	.99	4,113	5.29	2,418
Oct.	4.69	7,271	8.40	3,854	Oct.	1.40	4,156	7.13	2,639
Nov.	3.83	7,387	7.46	4,078	Nov.	1.23	4,184	5.66	2,808
Dec.	4.20	7,517	8.25	4,333	Dec.	.99	4,213	5.85	2,989
1931									
Jan.	4.25	7,649	7.97	4,581	Jan.	.87	4,239	6.09	3,179
Feb.	3.68	7,762	8.14	4,809	Feb.	.89	4,264	6.28	3,354
Mar.	4.02	7,887	8.06	5,059	Mar.	.89	4,293	6.22	3,548
Apr.	3.05	7,990	7.78	5,292	Apr.	.90	4,320	6.36	3,740
May	2.83	8,078	7.12	5,513	May	.91	4,348	8.33	3,947
June	3.84	8,193	7.44	5,737	June	1.24	4,385	12.55	4,324
July	3.76	8,310	13.39	6,152	July	1.25	4,424	12.67	4,717
Aug.	3.60	8,422	19.14	6,744	Aug.	1.29	4,464	11.61	5,076
Sept.	3.39	8,523	14.83	7,189	Sept.	1.38	4,506	11.75	5,430
Oct.	3.17	8,622	14.63	7,642	Oct.	1.29	4,546	12.17	5,807
Nov.	3.14	8,716	17.17	8,123	Nov.	.99	4,576	9.65	6,159
Dec.	3.08	8,812			Dec.	.98	4,606		
1932									
Jan.	2.94	8,903			Jan.	.90	4,635		
Feb.	2.72	8,983			Feb.	.83	4,659		
Mar.	2.65	9,065			Mar.	.75	4,684		
Apr.	2.58	9,143			Apr.	.82	4,707		
May	2.36	9,216			May	.71	4,729		
June	2.17	9,281			June	.69	4,750		
July	2.00	9,343			July	.69	4,771		
Aug.	1.97	9,403			Aug.	.67	4,791		
Sept.	1.72	9,455			Sept.	.68	4,811		
Oct.	1.86	9,513			Oct.	.63	4,837		
Nov.	1.68	9,563			Nov.	.58	4,854		
Dec.	1.52	9,612			Dec.	.60	4,873		
1933									
Jan.	1.41	9,656			Jan.	.58	4,891		
Feb.	1.36	9,694			Feb.	.51	4,907		
Mar.	1.27	9,733			Mar.	.62	4,924		
Apr.	1.28	9,772			Apr.	.52	4,945		
May	1.07	9,805			May	.49	4,960		
June	1.22	9,842			June	.49	4,975		
July	1.15	9,877			July	.47	4,989		
Aug.	1.06	9,910			Aug.	.43	5,003		
Sept.	.95	9,939			Sept.	.43	5,016		
Oct.	1.00	9,971			Oct.	.38	5,027		
Nov.	.95	9,999			Nov.	.41	5,040		
Dec.	.93	10,028			Dec.	.44	5,053		
1934									
Jan.	.91	10,057			Jan.	.43	5,067		
Feb.	.82	10,080			Feb.	.39	5,078		
Mar.	.86	10,107			Mar.	.42	5,090		
Apr.	.90	10,134			Apr.	.40	5,102		
May	.84	10,160			May	.39	5,114		
June	.76	10,183			June	.40	5,127		
July	.77	10,193			July	.42	5,132		

Table 125. Average daily and cumulative oil and water production by months of wells C and D in Flood No. 28, in barrels.

	Well C					Well D			
	Oil		Water			Oil		Water	
Date	Daily	Cumulative	Daily	Cumulative	Date	Daily	Cumulative	Daily	Cumulative
1928									
Sept.	2.24	67	1.15	36	Sept.	1.39	41		
Oct.	2.30	139	1.27	75	Oct.	1.83	98	.01	1
Nov.	1.48	183	1.29	114	Nov.	1.71	151		
Dec.	1.13	218	1.44	158	Dec.	1.67	202	.20	1
1929									
Jan.	.99	248	1.05	191	Jan.	1.53	250		
Feb.	.76	270	1.18	224	Feb.	1.73	300		
Mar.	.77	293	1.07	257	Mar.	1.39	344	.15	2
Apr.	.80	318	1.22	294	Apr.	1.43	387	.14	6
May	.80	342	1.50	340	May	1.54	433	.23	13
June	1.19	378	1.51	386	June	1.91	491	.28	22
July	1.60	428	1.57	434	July	2.54	570	.73	44
Aug.	1.83	485	1.67	485	Aug.	2.72	658	.95	74
Sept.	1.83	540	1.84	541	Sept.	2.96	746	1.04	105
Oct.	2.15	607	1.88	597	Oct.	3.47	853	.87	132
Nov.	2.67	687	1.86	655	Nov.	4.04	974	1.05	163
Dec.	2.90	779	1.98	717	Dec.	4.63	1,118	1.09	197
1930									
Jan.	3.47	887	1.98	777	Jan.	5.27	1,281	1.13	232
Feb.	4.12	992	1.98	831	Feb.	5.61	1,438	1.04	262
Mar	4.19	1,122	1.99	891	Mar.	5.75	1,617	1.05	294
Apr.	4.34	1,252	2.07	954	Apr.	5.97	1,796	1.23	331
May	10.36	1,574	2.29	1,024	May	36.90	2,940	.39	343
June	40.27	2,782	6.75	1,226	June	42.51	4,215	.49	358
July	28.17	3,658	5.45	1,395	July	25.86	5,006	.03	359
Aug.	19.61	4,266	4.12	1,523	Aug.	27.32	5,853	.12	363
Sept.	17.05	4,777	3.37	1,625	Sept.	15.58	6,320	1.38	405
Oct.	22.86	5,486	4.50	1,765	Oct.	18.11	6,882	4.74	551
Nov.	16.65	5,985	3.67	1,875	Nov.	11.99	7,242	5.49	716
Dec.	19.46	6,488	4.60	2,017	Dec.	12.15	7,619	6.73	925
1931									
Jan.	15.02	6,904	5.40	2,184	Jan.	10.20	7,935	8.19	1,179
Feb.	12.09	7,242	6.82	2,374	Feb.	8.55	8,175	9.35	1,441
Mar.	10.05	7,553	7.27	2,600	Mar.	7.74	8,407	9.09	1,723
Apr.	9.22	7,830	7.06	2,810	Apr.	5.87	8,583	9.70	2,014
May	11.15	8,176	10.39	3,132	May	6.89	8,796	14.73	2,471
June	16.17	8,661	18.67	3,692	June	6.04	8,978	19.88	3,068
July	16.60	9,176	23.25	4,414	July	1.27	9,017	13.76	3,473
Aug.	6.77	9,385	24.95	5,187	Aug.	1.29	9,057	11.86	3,841
Sept.	13.54	9,791	19.85	5,783	Sept.	4.62	9,196	26.50	4,636
Oct.	11.26	10,140	19.82	6,377	Oct.	4.23	9,327	30.23	5,573
Nov.	10.15	10,445	20.04	6,979	Nov.	3.82	9,441	28.60	6,431
Dec.	7.12	10,693			Dec.	2.24	9,521		
1932									
Jan.	7.31	10,924			Jan.	2.25	9,590		
Feb.	7.18	11,127			Feb.	1.99	9,648		
Mar.	6.10	11,316			Mar.	1.80	9,704		
Apr.	6.27	11,504			Apr.	1.94	9,762		
May	6.39	11,697			May	1.48	9,808		
June	5.75	11,870			June	1.38	9,849		
July	5.41	12,038			July	1.26	9,889		
Aug.	4.92	12,190			Aug.	1.14	9,925		
Sept.	3.36	12,304			Sept.	1.05	9,956		
Oct.	5.07	12,462			Oct.	1.07	9,990		
Nov.	4.06	12,583			Nov.	.98	10,019		
Dec.	3.56	12,694			Dec.	.92	10,047		
1933									
Jan.	3.34	12,797			Jan.	.92	10,076		
Feb.	3.24	12,888			Feb.	.80	10,098		
Mar.	2.80	12,975			Mar.	.77	10,121		
Apr.	2.90	13,062			Apr.	.73	10,143		
May	2.83	13,150			May	.69	10,164		
June	2.90	13,237			June	.61	10,183		
July	3.50	13,345			July	.88	10,210		
Aug.	2.81	13,426			Aug.	.59	10,228		
Sept.	2.37	13,498			Sept.	.49	10,243		
Oct.	2.30	13,569			Oct.	.50	10,258		
Nov.	2.16	13,634			Nov.	.47	10,272		
Dec.	2.03	13,697			Dec.	.47	10,287		
	Oil					Oil			
Date	Daily	Cumulative			Date	Daily	Cumulative		
1934									
Jan.	1.95	13,757			Jan.	.44	10,301		
Feb.	1.93	13,811			Feb.	.42	10,312		
Mar.	1.85	13,868			Mar.	.43	10,326		
Apr.	1.77	13,922			Apr.	.45	10,339		
May	1.81	13,978			May	.46	10,353		
June	1.73	14,029			June	.44	10,366		
July	1.70	14,052			July	.42	10,372		

Flood No. 29

Flood No. 29 is in the Burning Well pool about six miles east of Kane. The project whose production is discussed is in the small rectangle of Figure 102. In this area the intake wells were completed between January and November 1930, and the oil wells between June 1929 and February 1932. The distance between water intake wells is 300 feet and between water intake and oil wells, 212 feet. Water for flooding is obtained from two wells in the talus near the head of a small valley on the property. It is augmented by seepages from the Pottsville sandstones into which the valley has been cut. The water has a hydrogen ion concentration of almost eight parts per million. Lime is added to bring it to this concentration. A very little alum is added before filtering. The hydrogen ion concentration is checked twice a day. The pressure plant was started January 1930. Up to January 6, 1933, a

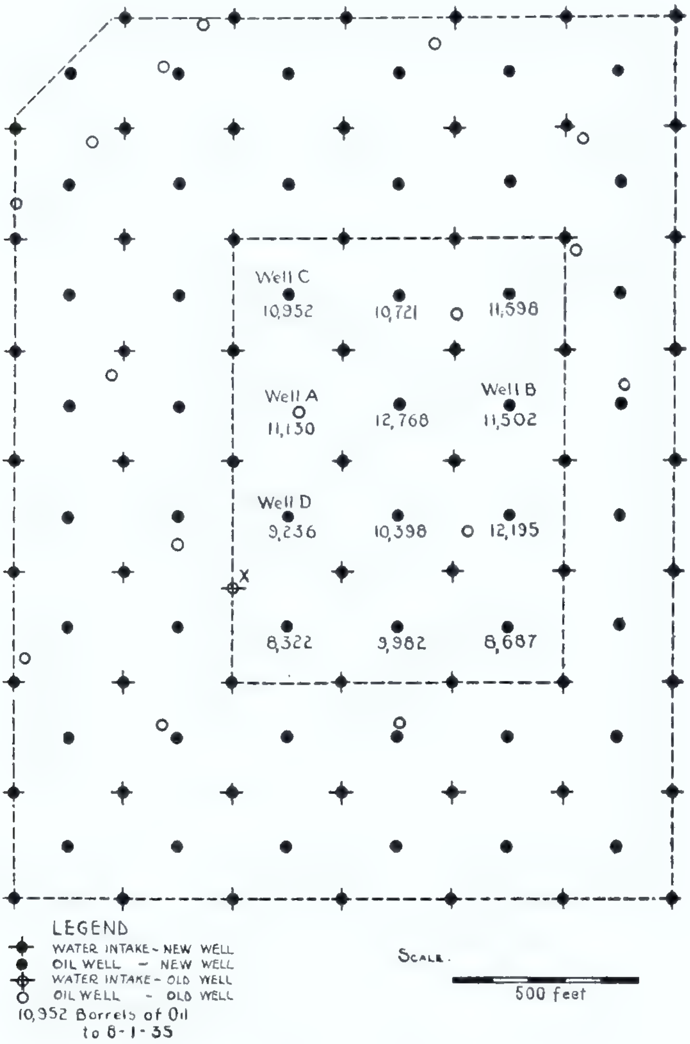


FIGURE 102. Map of Flood No. 29.

pressure equivalent to 1,500 pounds per square inch was maintained at the face of the sand in the intake wells. Since that time it has been raised to 1,600 pounds.

At the end of July 1935 the 24.79 acres in the small rectangle of Figure 102 had yielded 127,491 barrels of oil, an average of 5,143 barrels per acre. According to the drillers' records, the sand body has an average thickness of 43 feet. Of this, 34 feet or 79 percent is oil-bearing sandstone, making the yield per acre-foot 151 barrels. During July 1935 the average daily oil production per well was still 1.67 barrels with a water output to oil ratio of 4.11:1. The above figures will, therefore, be increased somewhat before the economic limit is reached.

The relation of fluid output to input for Flood No. 29 by years is given in Table 126. All water intake, but not all oil wells, had been completed by November 1, 1930. It will be noted that during the last nine months the fluid output was almost equal to the fluid input. The water input to oil ratio for the entire period was 3.33:1 and the water output to oil ratio 0.71:1. Between November 1, 1930, and November 1, 1931, the water input was 117,748 barrels or 4,758 barrels per acre, which is equivalent to 7.3 inches of water.

Table 126. Relation of fluid output to input for Flood No. 29 by years, in barrels.

Date	Oil production	Water output	Total fluid output	Water input
Prior to Nov. 1, 1930	3,033	163	3,196	73,987
Nov. 1, 1930, to Nov. 1, 1931	31,635	3,336	34,971	117,748
Nov. 1, 1931, to Nov. 1, 1932	49,191	13,186	62,377	90,339
Nov. 1, 1932, to Nov. 1, 1933	24,851	25,808	50,659	67,906
Nov. 1, 1933, to Nov. 1, 1934	12,578	27,506	40,084	46,428
Nov. 1, 1934, to Aug. 1, 1935	6,203	20,698	26,901	27,530
Total	127,491	90,697	218,188	423,938

The average daily and cumulative oil and water production and water input of the A, B, C and D units in Flood No. 29 are given in Tables 127 to 130, inclusive. The daily averages are shown graphically in Figures 103 and 104. In B unit, the oil well was drilled and put to pumping before the intake wells were completed. Nineteen months elapsed before production reached its peak. In C unit the drilling of the oil well was delayed 11 months, and in D unit 12 months. Well C reached its peak within nine months and well D within two months.

Well A is an old well whose location happened to fit into the five-spot pattern. Instead of drilling a new well it was cleaned out and used as a producing well. Although its final yield was somewhat greater than that of the average well in the tract, its behaviour was different in that the average daily peak production was less than half that of the other three wells. The intake well indicated by the X is also an old well which was cleaned out and utilized. Although the water input for this well was somewhat below the average for the group, at the end of the period under discussion it was still taking 10 barrels of water per day as compared to an average of eight barrels for the group.

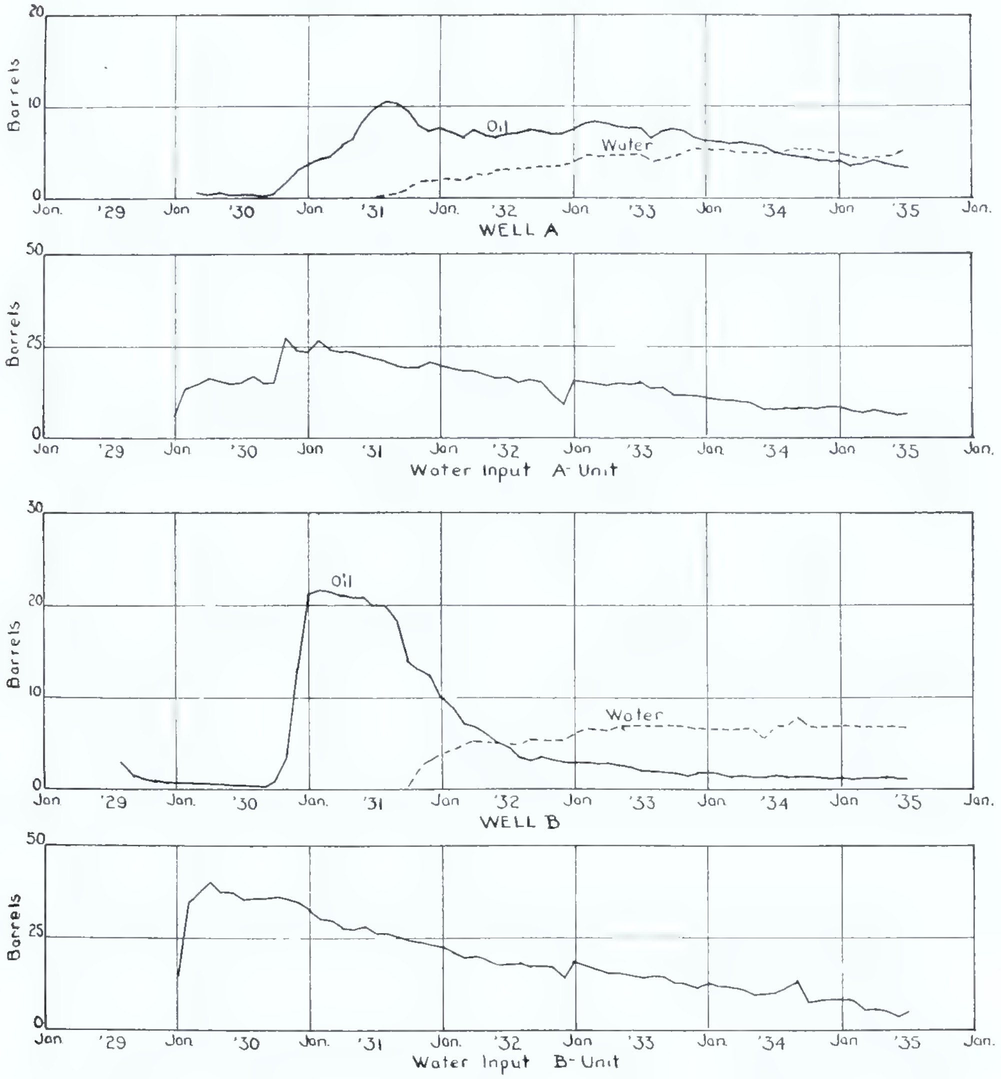


FIGURE 103. Curves showing average daily oil and water production and water input by months for A and B units in Flood No. 29.

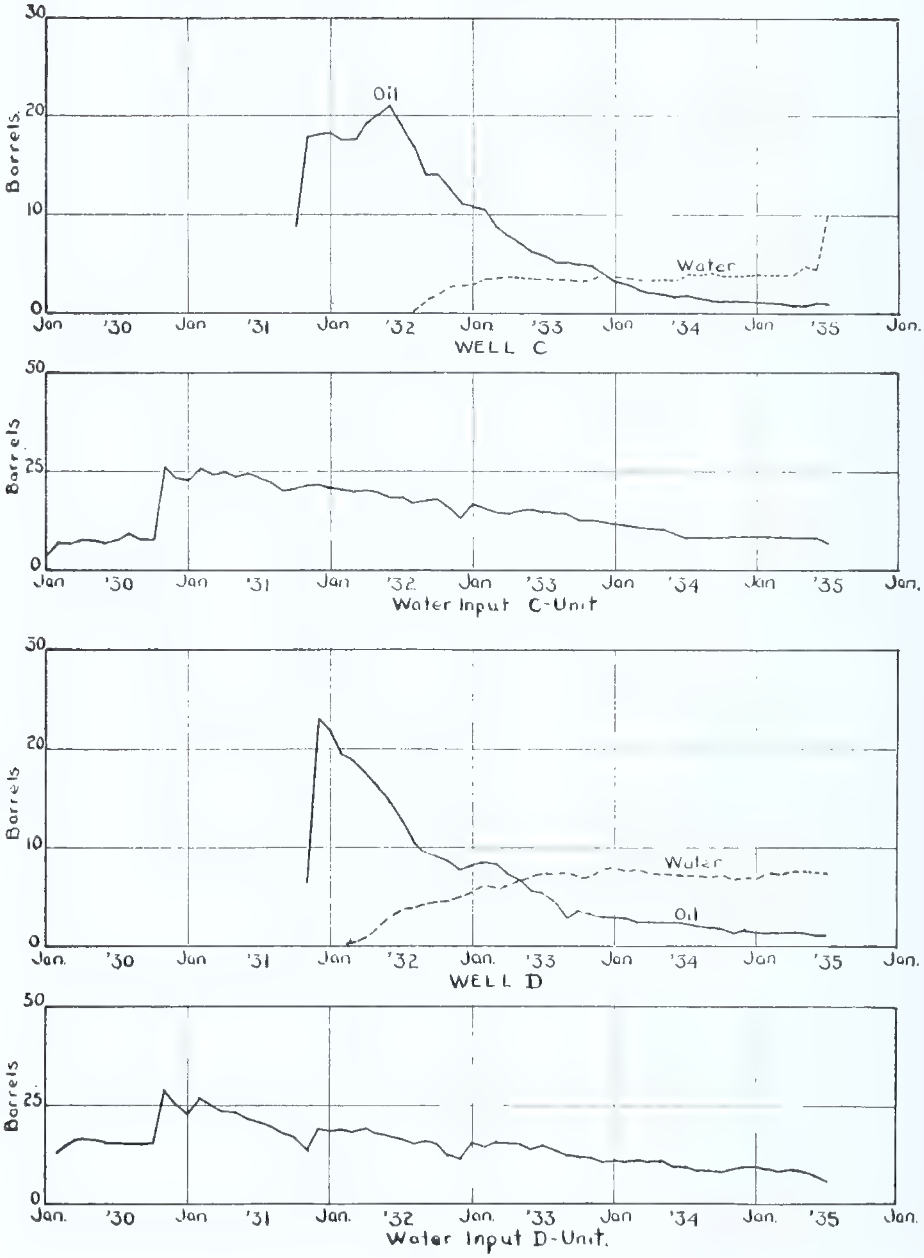


Figure 104. Curves showing average daily oil and water production and water input by months for C and D units in Flood No. 29.

Table 127. Average daily and cumulative oil and water production and water input of A-unit in Flood No. 29 by months, in barrels.

	Oil production		Water production		Water input	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative
1930						
January					6.3	197
February					13.5	576
March	.76	23			14.6	1,029
April	.42	36			16.2	1,512
May	.62	55			15.5	1,993
June	.38	67			14.8	2,435
July	.43	80			15.4	2,912
August	.39	92			16.9	3,387
September	.15	96			15.2	3,844
October	.62	116			15.2	4,316
November	1.72	167			27.6	5,146
December	3.07	263			23.8	5,890
1931						
January	3.73	378			23.3	6,583
February	4.29	499			26.5	7,299
March	4.70	644			24.2	8,052
April	5.42	807			23.5	8,752
May	6.41	1,005			23.5	9,481
June	8.59	1,263			22.5	10,158
July	9.82	1,568	.13	4	21.7	10,830
August	10.60	1,896	.35	15	20.9	11,476
September	10.40	2,208	.53	31	19.5	12,060
October	9.88	2,514	1.06	64	19.1	12,654
November	8.09	2,757	1.97	123	19.1	13,249
December	7.32	2,984	2.00	185	20.5	13,886
1932						
January	7.65	3,221	2.09	250	19.6	14,494
February	7.30	3,432	2.14	312	18.8	15,039
March	6.63	3,638	1.84	369	18.3	15,606
April	7.46	3,862	2.63	448	18.3	16,154
May	6.95	4,077	2.45	524	17.4	16,700
June	6.78	4,288	2.93	612	16.5	17,190
July	7.06	4,506	3.13	709	16.8	17,712
August	7.16	4,729	3.09	805	15.3	18,186
September	7.52	4,954	3.30	904	16.0	18,668
October	7.35	5,182	3.42	1,010	15.4	19,146
November	7.09	5,395	3.50	1,115	12.2	19,513
December	7.17	5,617	3.61	1,227	9.5	19,807
1933						
January	7.58	5,852	3.94	1,349	15.7	20,271
February	8.13	6,080	4.46	1,474	15.1	20,670
March	8.26	6,335	4.35	1,609	14.9	21,105
April	8.18	6,581	4.30	1,738	14.4	21,539
May	7.77	6,822	4.39	1,874	15.1	22,008
June	7.63	7,051	4.50	2,009	14.7	22,447
July	7.71	7,290	4.74	2,156	15.4	22,899
August	6.74	7,499	4.16	2,285	13.8	23,325
September	7.40	7,721	4.23	2,412	13.6	23,709
October	7.58	7,956	4.55	2,553	11.9	24,088
November	7.50	8,181	5.07	2,705	11.9	24,451
December	6.71	8,389	5.61	2,879	11.7	24,815
1934						
January	6.39	8,587	5.32	3,044	11.1	25,160
February	6.25	8,762	5.29	3,192	10.5	25,455
March	6.00	8,948	5.32	3,357	10.3	25,775
April	6.10	9,131	5.10	3,510	10.0	26,080
May	6.00	9,317	5.09	3,668	9.7	26,358
June	5.67	9,487	4.93	3,816	8.1	26,601
July	5.19	9,648	5.10	3,974	8.14	26,853
August	4.81	9,797	5.16	4,134	8.48	27,116
September	4.73	9,939	5.50	4,299	8.05	27,358
October	4.55	10,080	5.35	4,465	8.55	27,623
November	4.23	10,207	5.40	4,627	8.23	27,870
December	4.03	10,332	4.93	4,780	8.87	28,164
1935						
January	4.10	10,459	4.84	4,930	8.56	28,429
February	3.61	10,561	4.61	5,059	7.89	28,649
March	3.80	10,679	4.39	5,195	7.15	28,871
April	4.13	10,803	4.53	5,331	7.64	29,101
May	3.80	10,921	4.52	5.471	7.15	29,322
June	3.53	11,027	4.80	5,615	6.49	29,517
July	3.33	11,130	5.39	5,782	7.02	29,735

Table 128. Average daily and cumulative oil and water production and water input of B-unit in Flood No. 29 by months, in barrels.

Daily	Oil production		Water production		Water input	
1929	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative
July						
August	2.48	77				
September	1.68	127				
October	1.31	168				
November	.99	198				
December	.75	221				
1930						
January	.77	245			14.6	452
February	.60	262			34.3	1,412
March	.70	284			37.3	2,585
April	.60	302			40.1	3,789
May	.53	319			37.5	4,953
June	.49	334			37.3	6,042
July	.41	347			35.4	7,140
August	.34	358			35.9	8,253
September	.32	368			35.8	9,328
October	1.03	400			36.1	10,488
November	3.70	511			35.6	11,515
December	13.13	918			34.6	12,565
1931						
January	21.18	1,575			32.2	13,563
February	21.75	2,184			30.3	14,420
March	21.50	2,851			29.8	15,320
April	21.09	3,484			27.6	16,149
May	20.79	4,128			27.3	16,997
June	20.77	4,751			28.2	17,794
July	19.93	5,369			26.4	18,613
August	19.87	5,986			26.3	19,431
September	18.33	6,536			25.2	20,185
October	14.00	6,970	.39	12	24.6	20,947
November	13.10	7,364	2.53	89	24.1	21,671
December	11.40	7,717	3.13	186	23.2	22,390
1932						
January	9.90	8,024	3.94	308	22.8	23,080
February	8.94	8,283	4.38	435	21.2	23,693
March	7.37	8,512	4.84	585	19.8	24,307
April	6.71	8,713	5.30	744	20.0	24,906
May	6.12	8,903	5.26	907	19.1	25,501
June	5.30	9,062	5.00	1,057	17.6	26,055
July	4.55	9,203	4.97	1,211	18.0	26,613
August	3.76	9,320	4.81	1,360	18.2	27,153
September	3.30	9,419	5.77	1,533	17.5	27,683
October	3.69	9,534	5.45	1,702	17.5	28,225
November	3.26	9,632	5.47	1,866	17.3	28,719
December	3.07	9,727	5.52	2,037	14.2	29,185
1933						
January	3.13	9,824	6.13	2,227	18.4	29,755
February	2.90	9,906	6.54	2,410	17.5	30,223
March	2.76	9,991	6.45	2,610	16.5	30,712
April	2.86	10,077	6.37	2,801	15.6	31,180
May	2.68	10,161	6.71	3,009	15.6	31,665
June	2.50	10,236	6.87	3,215	14.6	32,105
July	2.16	10,303	7.00	3,432	14.3	32,549
August	2.16	10,370	6.84	3,644	14.8	32,983
September	1.96	10,429	7.03	3,855	14.5	33,415
October	1.77	10,484	6.97	4,071	12.7	33,809
November	1.76	10,537	6.93	4,279	12.8	34,195
December	1.93	10,597	6.68	4,486	11.7	34,559
1934						
January	1.96	10,658	6.61	4,691	12.9	34,952
February	1.82	10,709	6.50	4,873	12.0	35,289
March	1.64	10,760	6.35	5,070	11.8	35,656
April	1.73	10,812	6.53	5,266	11.3	35,969
May	1.51	10,869	6.74	5,475	9.6	36,258
June	1.57	10,916	5.70	5,646	9.8	36,552
July	1.71	10,969	6.84	5,858	10.1	36,866
August	1.55	11,017	7.00	6,075	11.4	37,219
September	1.67	11,067	7.90	6,312	13.6	37,628
October	1.48	11,113	6.87	6,525	7.7	37,866
November	1.60	11,161	6.60	6,723	8.1	38,110
December	1.39	11,204	6.65	6,929	8.5	38,373
1935						
January	1.42	11,248	6.84	7,141	8.3	38,631
February	1.25	11,283	6.89	7,334	8.3	38,864
March	1.45	11,328	6.65	7,540	5.5	39,035
April	1.40	11,370	6.63	7,739	5.7	39,206
May	1.52	11,417	6.68	7,946	5.2	39,366
June	1.40	11,459	6.67	8,146	3.8	39,481
July	1.39	11,502	6.52	8,348	5.04	39,637

Table 129. Average daily and cumulative oil and water production and water input of C-unit in Flood No. 29 by months, in barrels.

Date	Oil production Average	Oil production Cumulative	Water production Daily	Water production Cumulative	Water input Daily	Water input Cumulative
1930						
January					3.8	118
February					6.9	312
March					6.9	528
April					7.8	763
May					7.3	990
June					6.9	1,199
July					7.6	1,434
August					9.3	1,674
September					7.6	1,902
October					7.5	2,140
November					26.0	2,674
December					23.2	3,645
1931						
January					22.8	4,325
February					25.9	5,026
March					24.1	5,775
April					24.9	6,517
May					23.9	7,257
June					24.5	7,984
July					23.2	8,702
August					22.1	9,382
September					20.4	9,994
October	8.88	275			20.6	10,632
November	17.97	814			21.4	11,296
December	18.20	1,379			21.6	11,965
1932						
January	18.32	1,946			20.9	12,613
February	17.55	2,455			20.3	13,200
March	17.55	2,999	.10	3	19.9	13,816
April	19.26	3,577	.03	4	20.2	14,421
May	20.14	4,202	.00	4	19.6	15,027
June	21.01	4,832	.03	5	18.5	15,582
July	19.27	5,429	.09	8	18.4	16,153
August	16.96	5,955	.25	16	17.1	16,682
September	14.15	6,380	1.50	61	17.7	17,215
October	14.03	6,815	1.97	122	18.1	17,774
November	12.07	7,196	2.60	200	15.9	18,253
December	11.08	7,539	2.71	284	13.1	18,659
1933						
January	10.68	7,871	3.09	380	16.6	19,181
February	10.40	8,162	3.71	484	15.7	19,597
March	8.80	8,435	3.68	598	14.6	20,049
April	7.95	8,673	3.87	714	14.3	20,477
May	7.22	8,897	3.68	828	15.1	20,946
June	6.27	9,085	3.70	939	15.5	21,410
July	5.97	9,270	3.65	1,052	15.0	21,876
August	5.32	9,435	3.52	1,161	14.6	22,323
September	5.33	9,595	3.53	1,267	14.2	22,725
October	4.97	9,749	3.35	1,371	12.9	23,135
November	4.60	9,887	3.50	1,476	12.6	23,513
December	4.06	10,013	3.90	1,597	12.2	23,892
1934						
January	3.39	10,118	3.81	1,715	11.8	24,257
February	2.93	10,200	3.75	1,820	11.3	24,574
March	2.35	10,273	3.52	1,929	10.8	24,910
April	2.20	10,339	3.57	2,036	10.5	25,229
May	2.03	10,402	3.61	2,148	10.3	25,547
June	1.77	10,455	3.47	2,252	9.24	25,825
July	1.87	10,513	3.94	2,374	8.6	26,091
August	1.55	10,561	3.90	2,495	8.7	26,361
September	1.37	10,602	4.07	2,617	8.3	26,609
October	1.32	10,643	3.87	2,737	8.5	26,874
November	1.33	10,683	3.77	2,850	8.3	27,124
December	1.32	10,724	3.74	2,966	8.6	27,415
1935						
January	1.29	10,764	4.00	3,090	8.7	27,685
February	1.14	10,796	3.86	3,198	8.6	27,927
March	1.10	10,830	3.97	3,321	8.6	28,193
April	.97	10,859	4.07	3,443	8.3	28,441
May	.94	10,888	4.74	3,590	8.4	28,701
June	1.10	10,921	4.47	3,724	8.2	28,949
July	1.00	10,952	10.19	4,040	6.8	29,160

Table 130. Average daily and cumulative oil and water production and water input of D-unit in Flood No. 29 by months, in barrels.

Date	Oil production Daily	Oil production Cumulative	Water production Daily	Water production Cumulative	Water input Daily	Water input Cumulative
1930						
January					5.7	176
February					13.4	555
March					15.3	1,031
April					16.5	1,525
May					16.1	2,024
June					15.5	2,488
July					15.4	2,967
August					15.1	3,438
September					15.2	3,895
October					15.3	4,369
November					28.6	5,301
December					25.3	6,084
1931						
January					23.1	6,800
February					26.8	7,550
March					24.9	8,321
April					23.8	9,036
May					23.3	9,758
June					21.9	10,416
July					21.0	11,068
August					20.0	11,686
September					18.0	12,226
October					17.2	12,758
November	6.52	195			14.4	13,267
December	23.12	912			19.1	13,857
1932						
January	21.95	1,582			18.4	14,428
February	19.52	2,148	.10	3	19.0	14,980
March	18.70	2,728	.58	21	18.7	15,561
April	17.67	3,258	1.27	59	19.3	16,141
May	16.10	3,757	2.19	127	18.2	16,703
June	14.72	4,199	3.00	217	17.3	17,224
July	12.82	4,596	3.84	336	16.7	17,744
August	10.43	4,919	3.97	459	15.3	18,219
September	9.51	5,205	4.37	590	16.2	18,705
October	9.35	5,494	4.65	734	15.4	19,183
November	8.71	5,756	4.77	877	12.7	19,565
December	7.88	6,000	5.19	1,038	11.5	19,923
1933						
January	8.34	6,259	5.74	1,216	15.6	20,382
February	8.59	6,499	6.21	1,390	14.7	20,793
March	8.40	6,760	5.90	1,573	15.8	21,257
April	7.62	6,988	6.23	1,760	15.4	21,718
May	6.72	7,197	6.74	1,969	15.3	22.193
June	5.83	7,372	7.23	2,186	14.1	22,618
July	5.48	7,542	7.45	2,417	14.9	23,051
August	4.45	7.680	7.39	2,646	13.8	23,478
September	3.07	7,772	7.50	2,871	12.4	23,854
October	3.77	7,889	7.09	3,091	12.1	24.231
November	3.43	7,992	7.30	3,310	11.9	24,593
December	3.10	8,088	7.97	3,557	11.0	24,935
1934						
January	2.94	8,179	8.09	3,808	11.4	25,288
February	2.71	8,255	7.79	4,026	10.8	25,590
March	2.39	8,329	7.84	4,269	11.3	25,933
April	2.57	8,406	7.67	4,499	10.9	26,258
May	2.55	8,485	7.48	4,731	10.2	26,549
June	2.47	8.559	7.43	4,954	9.4	26,829
July	2.32	8,631	7.16	5,176	9.5	27,123
August	2.16	8,698	7.16	5,398	8.6	27.389
September	2.13	8,762	7.03	5.609	8.6	27,647
October	1.97	8,823	7.26	5,834	8.3	27,903
November	1.50	8,868	6.87	6,040	9.1	28,177
December	1.77	8,923	7.06	6,259	9.8	28,482
1935						
January	1.52	8,970	7.10	6,479	9.9	28,787
February	1.46	9,011	7.50	6,689	9.2	29.045
March	1.52	9,058	7.39	6,918	8.7	29,313
April	1.67	9,108	7.80	7.152	9.1	29,587
May	1.61	9.158	7.74	7,392	8.6	29,853
June	1.30	9,197	7.67	7,622	7.7	30.085
July	1.26	9,236	7.42	7,852	6.2	30.278

Summary of Production Data for Various Types of Floods

Production data for the various types of floods discussed in the preceding section are summarized in Table 131. Although none of the intensive floods had reached their economic limit at the end of the period for which the production is given, in most cases such a stage had been reached that the quantity remaining to be recovered by the methods now in use would not add appreciably to the total recovery calculated on a per acre or a per acre-foot basis.

As the thickness of the Bradford Third sand and the percentage that is oil-bearing varies within rather wide limits over different parts of the Bradford field, for purposes of comparison the recovery per acre-foot has been calculated on the basis of the thickness of oil-bearing sandstone estimated to be present under each tract. The average thickness of the entire sand body was calculated from the drillers' records. The percentage of this which is oil-bearing sandstone was obtained either from the measurement of cores or from the examination of drill cuttings taken on or near the property.

Table 131. Summary of production data for various types of floods.

Flood No.	Type of Flood	Area in Acres	A Feet	B Feet	C Lbs.	D Bbls.	E Bbls.	F Ratio	G Ratio	H Bbls	I Ratio
1	Circle	35.9		30	600	5,623	187				
2	Circle	9.7		26	600	3,754	144				
3	Circle	21.8		24	490	5,175	216				
4	Circle	30.7		24	585	3,294	137				
5	Circle	12.3		28	525	4,619	165				
6	Circle	4.0		43	555	5,013	117				
7	Circle	135.0		24	700	3,027	126				
8	Circle	20.2		20	875	2,637	132				
9-W	Circle	16.5		19	700	3,804	200				
9-E	Circle	30.0		24	850	5,694	237				
10	Line	16.6	152	24	700-785	4,275	178				
11	Line	3.5	170	28	675	4,280	153				
14	5-spot	25.0	190	29	625-1025	6,777	234			.47	
15-I	5-spot	13.41	180	38	800-1000	5,651	149		1.73	.67	15.0
15-K	5-spot	1.49	180	36.5	800-1000	8,988	246		1.53	.89	13.0
16	Mod. 5-spot	3.14		31	760-1050	7,276	235		1.89		
16-D	Mod. 5-spot	1.32		28	760-1050	7,280	260		.76	1.00	20.0
17	Mod. 5-spot	13.20	210	34	810-960	7,483	220	4.90	1.71	1.60	12.0
18-S	5-spot	28.8	200	26	720-970	5,014	193			1.58	
18-N	5-spot	30.6	200	28	720-970	5,266	188			1.47	
19	5-spot	4.37	154	38	700	7,131	188		2.85	.60	25.0
20	5-spot	63.8	152	42	715-835	4,850	115	7.33		1.54	
22	5-spot	16.38	244	25	1200	2,065	83			1.09	3.11
23-AB	5-spot	2.9	178	31	940	5,947	192	12.84		1.61	
23-D	Mod. 5-spot	1.9		34	940	6,211	182			1.35	
24	5-spot	13.67	223	22	885-1335	1,537	70	26.0		1.44	
25	5-spot	34.5	224	31	900-1550	1,921	62			.72	
26	Mod. 5-spot	26.26	193	35	800	4,679	142			3.86	
27	5-spot	18.0	198		1700	1,620				1.43	
28	5-spot	72.0	198		540-1200	6,020				.65	
29	5-spot	24.79	212	34	1500-1600	5,143	151	3.33	.71	1.67	4.11

A. Distance between intake and producing wells.
B. Average thickness of oil-bearing sandstone.
C. Pressure at face of sand in intake wells in pounds per square inch.
D. Oil recovered per acre.
E. Oil recovered per acre-foot.
F. Water input to oil ratio for entire period.
G. Water output to oil ratio for entire period.
H. Average daily oil production per well at end of period.
I. Water output to oil ratio at end of period.

Relation of Production of Oil by Water-flooding to Physical Characteristics of Sand

A close relationship exists between the physical properties of the Bradford Third sand and the success attained with water flooding. Cores 4, 6, 7, 9, and 11 came from some of the most successful flood areas. The ideal sand for water flooding as shown by these cores appears to be one in which practically all its grains are less than 0.2 millimeters in diameter, with an average grain diameter between .04 and .05 millimeters, and the porosities of its different members falling within the limits of 14 to 16 percent and their permeabilities between 5 and 10 millidarcys. It possesses an average oil saturation of 45 or more percent.

From the standpoint of permeability, core No. 11 represents an ideal condition. It will be observed from the permeability profile of this core, shown in Plate 17, that the maximum permeability is only 9.09 millidarcys and that the permeabilities of each of the important layers of sandstone in the sand body fall within about the same range. Flood No. 16 on the tract from which this core came yielded an exceptionally high recovery per acre-foot of oil-producing sand with a low water output to oil ratio.

In the Knapp Creek gas cap in the northeastern part of the Bradford field and the Rixford gas cap southwest of Rixford, the upper part of the Bradford Third sand, which originally contained large volumes of gas and only a little oil, frequently has a considerably higher permeability than that of the underlying oil "pay". This condition is illustrated by core No. 2 whose permeability profile is shown in Plate 16. In spite of the fact that considerable care is usually exercised in packing off the gas "pay", trouble from bypassing of the water is experienced in these areas. The water input and water output to oil ratios are high, as shown by Floods 23, 24 and 25. The fact that in Flood No. 14, near the southwestern margin of the Knapp Creek gas cap, only 25 percent by volume of the daily input water was being accounted for by the oil and water output after the flood had been in operation for four years, would seem to indicate that large volumes of water are not only entering the gas "pay" under the property but are probably also moving into adjacent areas not yet under pressure. In Flood No. 25, only 44 percent of the daily input water was accounted for in the output after the flood had been in operation for 3½ years. In marked contrast, the daily oil and water output at the end of four years was nearly equal to the water input in Floods 15 and 29, and Flood No. 17 was equivalent to 80 percent of the input at the end of four years.

The so-called "loose streaks" in certain parts of the Bradford field, particularly the eastern lobe, but not restricted entirely to it, have been mentioned. These are much more permeable than the average Bradford Third sand. Core No. 18, whose permeability profile is shown in Plate 18, illustrates such a condition. The results obtained in Flood No. 26, located on a narrow belt of highly permeable sand representing such a "loose streak" along the eastern margin of the Rixford gas cap, indicate that satisfactory recoveries may be expected where the highly permeable layers constitute a large enough percentage of a normal thickness of sand body and possess a sufficiently high oil saturation, but that the water input and water output to oil ratios will be much higher than in areas of more normal conditions. Floods in "loose streaks" will probably reach their economic limit before any layers of sand having only average permeabilities are watered out.

The degree of saturation of the oil-bearing sandstone is an important factor in determining recoveries. The K-unit of Flood No. 15, from which core No. 9 came, showed an unusually high recovery per acre-foot of oil-bearing sandstone. Analyses showed an average oil saturation of 46.5 percent for the top "pay" and 40 percent for the bottom "pay". When the flood had about reached its economic limit, 51 percent of the oil content, calculated on a per acre basis, had been recovered. The oil "pay" in core No. 3, from the D-unit of Flood No. 23, had an average oil saturation of 36.3 percent. When this flood was approaching its economic limit, 45 percent of the oil content had been recovered. In contrast, in core No. 2 from the tract on which Flood No. 24 is located, the oil "pay" had an average oil saturation of only 29 percent. When this flood was approaching its economic limit, only 22 percent of the quantity of oil shown by the core analysis had been recovered. The low recovery on this tract, however, is probably due not alone to the relatively low saturation of the oil "pay" but also to the marked difference in permeability of the various sand layers.

In a homogeneous inclined sand stratum, Wycoff, Botset and Muskat[87] have shown that it would be advantageous to flood up the dip, as under these conditions there is less tendency for cusping or fingering and the water advances more uniformly. In much of the Bradford field, however, the dips are so slight that the irregularities in the sand body far outweigh any effect that structure may have on the advance of the water-oil interface through the individual layers of sand. The intensive method of water flooding now in use in the Bradford field does not lend itself to adjustment to the structural contour of the sand.

The spacing between water input and oil wells now in use has been determined largely by long experience. In some of the earlier "five-spot" developments, distances between water intake and oil wells were as low as 150 feet. Now 200 to 225 feet is a more common distance. A study of Table 131 reveals that this increase has not resulted in any decrease in oil recovery per acre-foot of oil-bearing sandstone. It has, on the other hand, resulted in a considerable decrease in development and hence in production costs. It is doubtful, however, whether it would be advisable to widen the spacing still further on account of the marked variations in the character of the sand within relatively short distances. The presence of irregularities, such as those exhibited by wells C and D in Flood No. 28, would frequently result in the loss of much oil if spacing were too wide. In exceptionally thick bodies of sand containing shale seams, it may even be advisable to shorten this distance if core analyses show a sufficiently large oil content per acre. The local sand conditions should be considered in determining the spacing for a particular tract.

Concomitant with the increase in distance between input and producing wells, pressures at the face of the sand in the intake wells have also been increased. Pressures ranging from 1,000 to 1,500 pounds with the wider spacing have proved satisfactory in areas where sand conditions are normal.

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[87] R. D. Wycoff, H. G. Botset and M. Muskat, The mechanics of porous flow applied to water-flooding problems: Trans. Am. Inst. Min. Eng., vol. 103, 1933, pp. 236-237.

Where the major portion of the sand has a relatively high permeability, as in Flood No. 26, a lower pressure than the one used probably would have resulted in lower water input and water output to oil ratios and quite probably a greater recovery per acre-foot of oil-producing sand, but the rate of recovery would have been reduced. It has been shown, experimentally at least, that, if production is too rapid, the water will show a decided tendency in cusping or fingering toward the producing well. [88]

With a spacing of 200 to 215 feet between intake and producing wells, and a pressure of 1,000 to 1,500 pounds at the face of the sand in the intake wells, in areas where the sand has a normal development, between 80 and 90 percent of the oil recoverable by water flooding is obtained during the first four years that the flood is in operation. Water input to oil ratios of those floods studied for which the data were available ranged all the way from 3.33:1 to 26:1. Ratios above 10 were confined to floods in areas where the oil "pay" is overlain by a gas "pay". In these areas the quantity of water produced with the oil during the later stages of production was so large that it was not feasible to gauge it. In the floods with the lower input ratios, the water output to oil ratios ranged from 0.71:1 to 2.85:1 for the periods covered by the production data. Unfortunately data on water input and output were not available for Flood No. 26, in the area of highly permeable sand.

Intake wells take water most rapidly at the start. The rate then declines, at first rapidly and later much more slowly. Operators sometimes offset this decline by increasing the pressure. A study of the results obtained seems to indicate that little if anything is gained by this practice during the later stages of a flooding operation as the rate of oil production is not appreciably increased thereby, but usually there is a considerable increase in the water output to oil ratio.

Although delayed drilling on the properties studied gave no definite indication of an appreciably greater recovery, it has undoubtedly resulted in a saving in operating costs. The same amount of oil is recovered in less time and usually the water output is somewhat less.

In discussing the oil content of core No. 9, it was pointed out that only about half of the pore space of the sand was accounted for by the oil shown by the core analysis to be present and the oil already removed. In Floods 17 and 29, data on both water input and output were available for periods of 5 to 5½ years. The fact that in Flood 17 the oil and water output was only 55 percent of the water input and in Flood 29, 51 percent, would seem to indicate that the entire pore space was not filled with liquids, such as oil and water, when the first wells were drilled, but that much space was occupied by free gas. In these tracts this gas was not segregated in the upper part of the sand body but apparently was distributed throughout the oil "pay."

As a general rule, those areas in which the yield per acre by the ordinary production methods was high have also given the best results when later subjected to water flooding. Unusually high recoveries by water flooding have been obtained in the area from which cores 4, 6, 9 and 11 came. In this area the natural recovery per acre also was high. In the Bradford lease of Bird and Ball, as pointed out on page 293, the natural production amounted to

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[88] H. D. Wilde, Jr., The value of gas conservation and efficient use of a natural water-drive as demonstrated by laboratory models: Production Bull. 210, Amer. Petrol. Inst., 1932, pps. 4-10.

5,450 barrels per acre as compared with an average of 2,424 barrels for the entire field. There have been some exceptions to the above rule, however. Flood No. 4 is an example. On this tract of 37 acres, developed originally by eight wells, the natural production was only 1,141 barrels per acre in contrast to a yield of 3,294 barrels per acre by water-flooding. The tract is near the northern edge of the pool. When it was first developed the reservoir pressure had probably already been reduced considerably and it was, therefore, not as closely drilled as most parts of the field on account of the low initial production of the wells. As a result, the natural production calculated on a per acre basis was low.

In developing tracts containing old floods, care has to be exercised not to drill producing wells at points where most of the sand body has already been watered-out. Attempts to drive oil toward such wells from areas that have not yet been reached by the flood waters have not proven successful. This subject has been discussed in connection with the behavior of Well D in Flood No. 17. In delayed drilling of oil wells, trouble may arise from this source if the bank of oil that is built up ahead of the water does not develop symmetrically around the center of the pattern, owing to sand irregularities, and the water reaches the site of the producing well before it is drilled.

Unless the characteristics of the sand body are already definitely known from the results obtained on adjacent properties, it is always advisable to take several cores of the sand on a property before undertaking an extensive water-flooding program. Thicknesses and characteristics of the sand body as determined by the drill and by the examination of the cuttings should be recorded for each well. If this information is available, the behavior of the input and producing wells can later be interpreted more intelligently. This, in some instances, may indicate points where it may be profitable to drill additional wells, either intake or producing. The results obtained by drilling an additional water intake between wells C and D of Flood No. 28 is an example of what can sometimes be accomplished in this manner.

Equipment and Operating Methods

The process of water flooding consists of applying water under pressure to the oil-bearing horizon through water intake wells so located that the bank of oil, which accumulates ahead of the advancing water as the latter permeates the sand, is forced toward producing wells. The "five-spot" arrangement, in which each producing well is surrounded by four intake wells, and occasionally the "seven-spot", in which each producing well is surrounded by six intake wells, are the patterns at present used. The layout of a typical water-flooding operation is shown diagrammatically in Figure 105. The equipment used in intake and producing wells, where the water is introduced at the top of the intake wells, is shown in Figure 106 and where subsurface water is used, in Figure 107. The latter method of introducing water to the producing horizon is now rarely used in the Bradford district.

In laying out a pattern for a flooding operation, no attention is paid to the location of old wells on the property. These either are pumped along with the new producing wells until they are watered out or they are plugged. Occasionally an old well, if it happens to fit rather closely into the pattern, may be cleaned out and used either as a producing or an intake well, depending upon its location.

Drilling and casing. The cable tool or percussion system is used exclusively for drilling wells. In most cases, semi-portable drilling rigs or portable drilling machines are employed, but the standard rig, constructed of wood, has not entirely disappeared. Gasoline and steam engines and occasionally electric motors furnish the power for drilling.

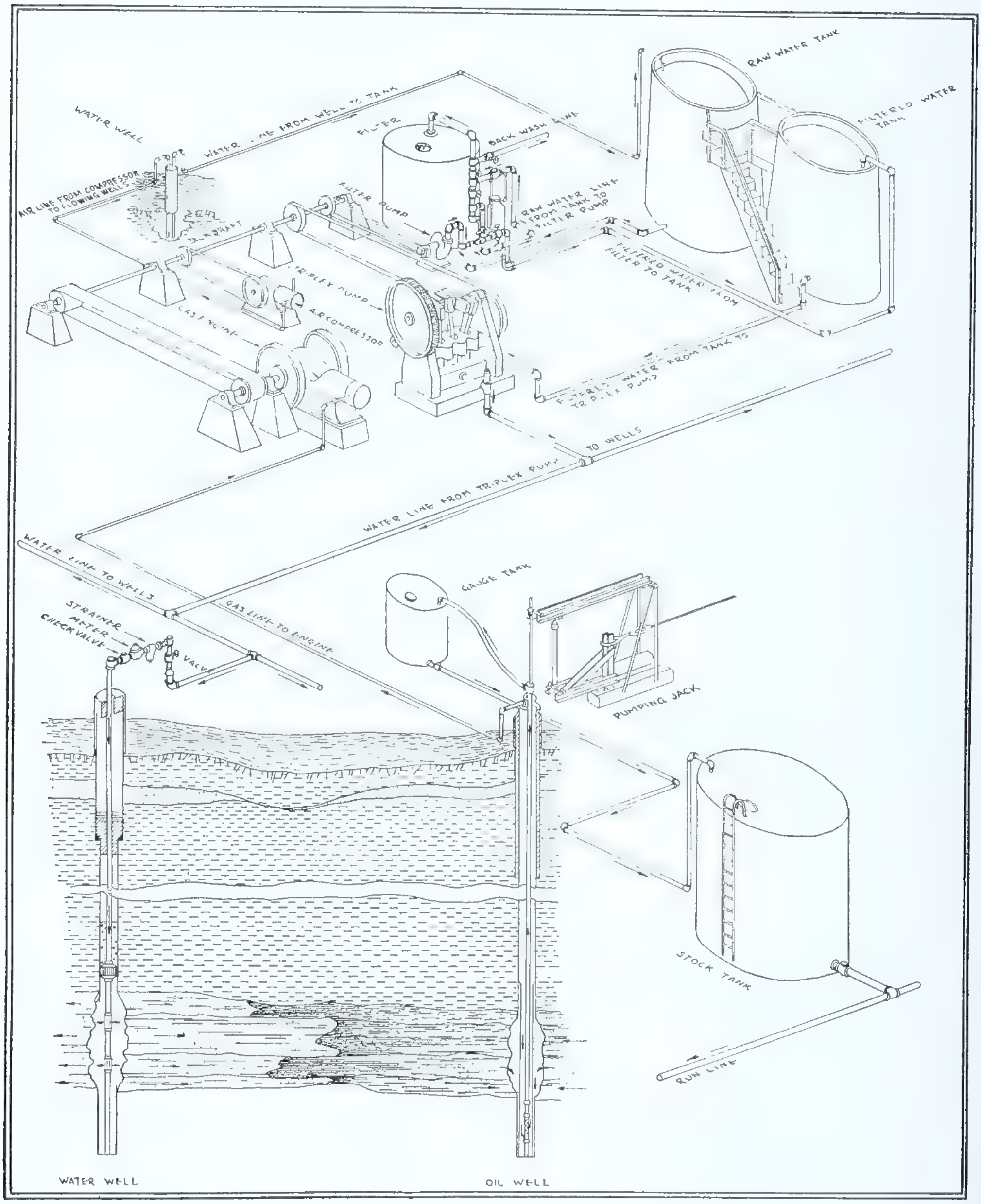

FIGURE 105. Diagram showing layout of a typical water-flooding operation.

Ordinarily from 30 to 40 feet of 8¼-inch drive pipe, weighing 17 pounds per foot, or a wood conductor is used in starting a well. In the alluvial filled valleys, however, considerably greater lengths of drive pipe are required, up to 250 feet in some localities. With the exception of the Olean and Knapp conglomerates and sandstones which immediately underlie the plateau in the southern part of the district, the bed-rock formations of the Bradford field contain no well-defined water-bearing horizons. Shallow ground water is confined to fractures relatively near the surface and occasional sandy lenses in the upper zone. The average lower limit at which ground water is encountered is 360 feet and rarely exceeds 500 feet regardless of the horizon at which a well starts. Casing 6¼ inches in diameter, weighing 13 pounds per foot, is used to shut off this water.

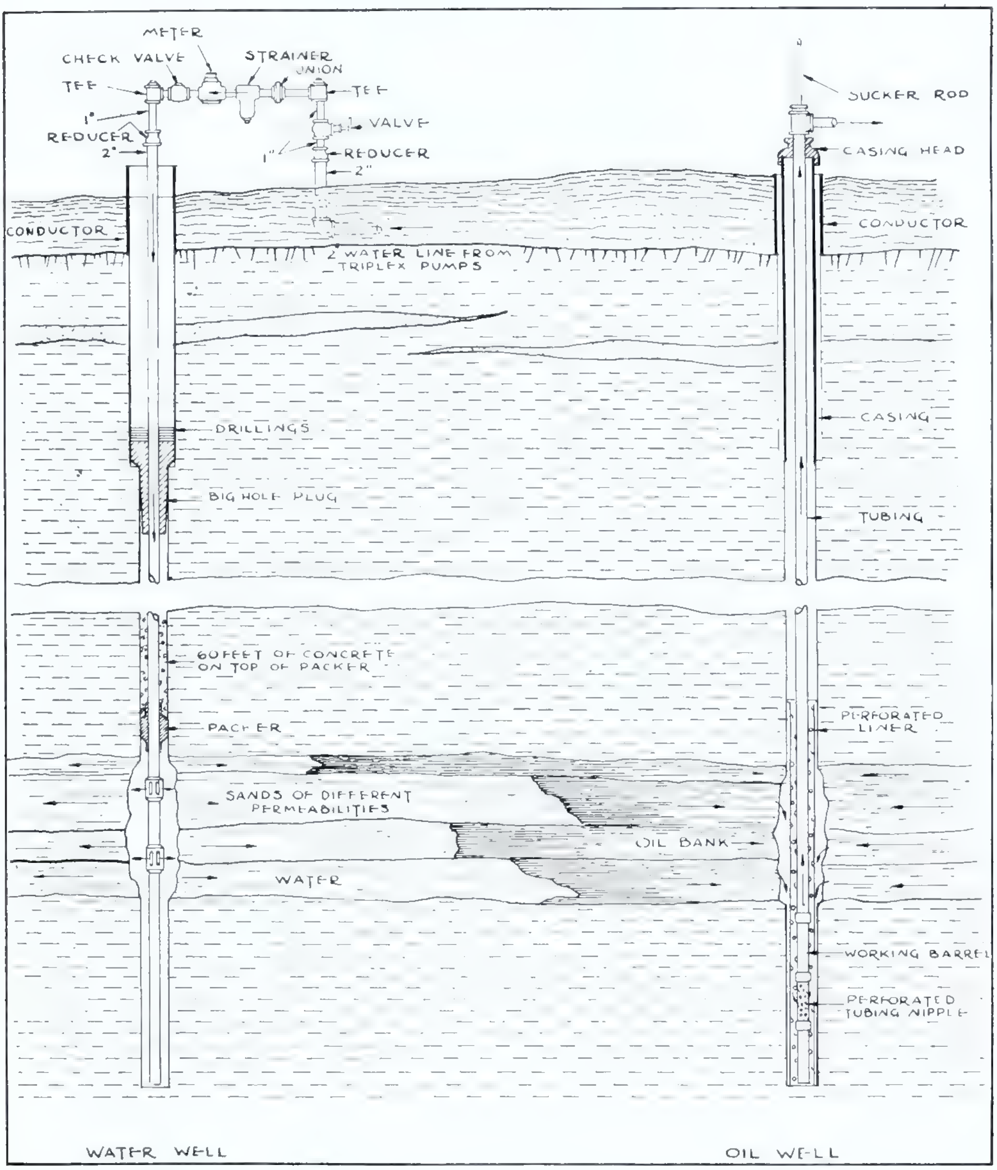

Figure 106. Sketch showing equipment of intake and producing wells — water introduced at top of intake wells.

In the northern part of the district along Nichol Run and the headwaters of Chipmunk Creek, the Bradford First sand frequently contains so much salt water that this has to be shut off. In that case, 10-inch drive-pipe is used and the shallow ground water is shut off with 8¼-inch casing and the salt water in the Bradford First sand with the ¼-inch. In a few instances setting casing too deep in one well has resulted in admitting water through one of the deeper sands to nearby wells. Such a case is illustrated in Figure 108. The Sugar Run sand, at a depth of 586 feet, contained a little salt water which was not cased off in the well at the left as it gave no particular trouble. Later the well at the right was drilled and cased through this sand. Shallow fresh water from above was thereby admitted to the sand and flowed along it until it entered the well at the left.

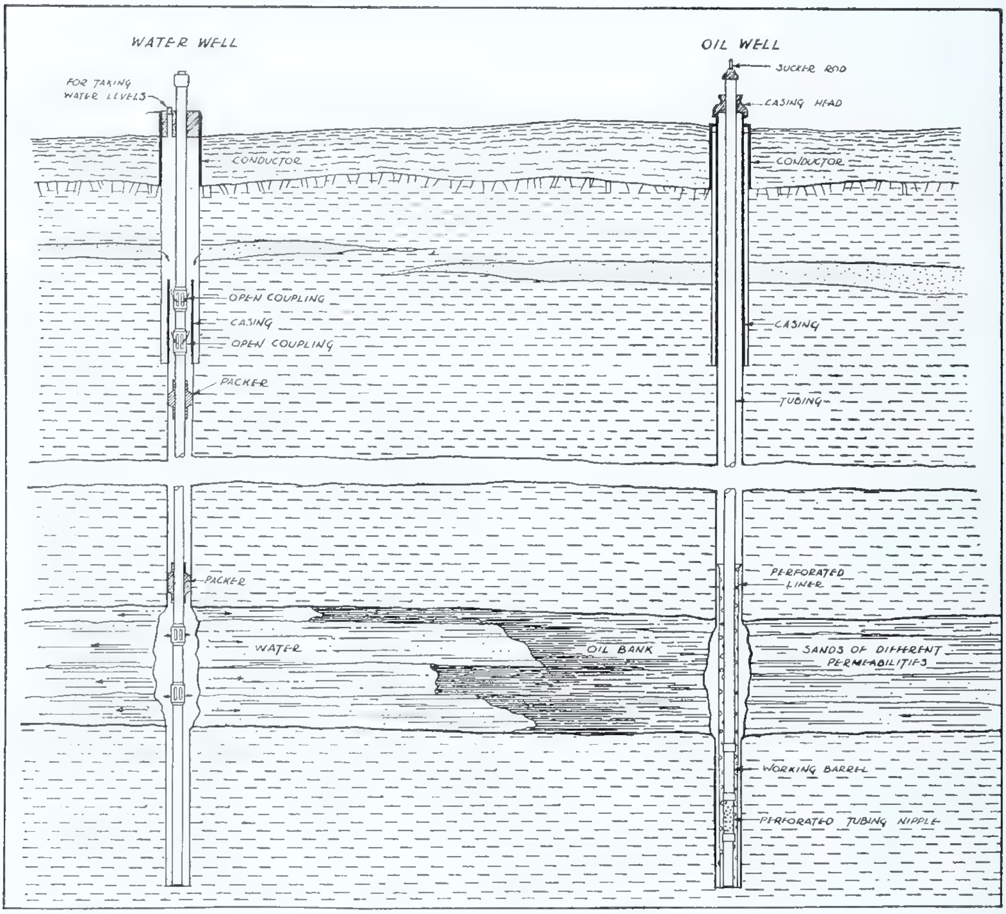

FIGURE 107. **Sketch showing equipment of intake and producing wells—subsurface water introduced into intake wells.**

Wells are usually drilled deep enough to provide a 25-foot pocket below the bottom of the sand in the intake wells and 50 feet in the producing wells. Wells in the Bradford field deviate but little from the vertical. Simmons,[89] who has surveyed a considerable number with a Sperry-Sun clinograph, found maximum deviations of only 1½°. Drilling is done mostly by contractors. Only a few companies employ their own drilling crews. Ordinarily from 16 to 32 days are required to complete a well, depending upon the depth and whether both day and night "tours" are run.

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[89] Arthur Simmons, Crooked holes in the Bradford Field and their possible effect on five-spot operations: Bradford District Oil Producers' Bull., vol. IV, pp. 1, 3 and 4, February, 1934.

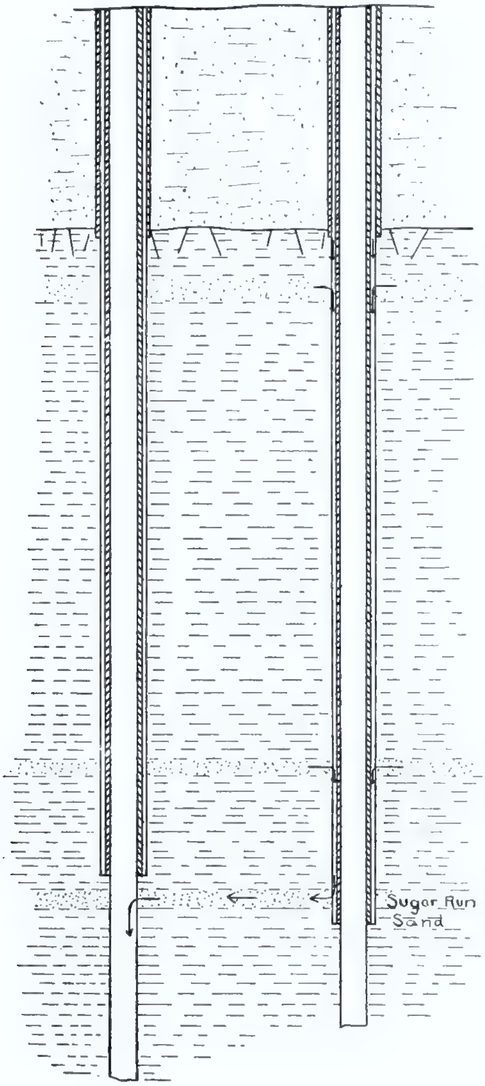

FIGURE 108. Diagram showing how setting casing too deep in one well may admit water to a nearby well.

Both intake and producing wells are shot. The experience has been that wells which are not shot do not give good results. An average of 80 to 90 quarts of nitroglycerine is used to shoot a well, the quantity depending upon the thickness of the sand and the judgment of the operator as to the diameter of shell to use. Shells of different diameter frequently are used opposite the various sand layers that constitute the sand body. Common sizes are 3½- and 4-inch. It takes 5 feet, 1.8 inches of 3½-inch shell and 3 feet, 11.5 inches of 4-inch, to hold ten quarts. The loading of a shell is shown in Plate 20-B. The operator determines the size, spacing, and position of the shot and the torpedo or shooting company takes care of the rest. Where a gas "pay" overlies the oil "pay", a setting point for the packer in the intake wells is selected and the top of the shot is placed nine feet below this point so that the sand body in the vicinity of the packer will not be fractured.

Cores. Two methods of taking cores have been used in the Bradford field: one with the diamond drill and the other with the cable-tool core barrel.

For taking cores with a diamond drill, a double-tube core barrel with a bit capable of taking a core 2¼ inches in diameter is used ordinarily. The wells are drilled first with cable-tools to within 5 or 10 feet of the top of the sand, as calculated from the logs of nearby wells. A string of 4¼-inch casing is then set on the bottom of the hole and the diamond drilling is done through it to prevent excessive vibration of the drill pipe. In wells much deeper than 800 feet, smaller casing is used, with special collars on the outside to hold it firmly in place, or else two strings of casing. For diamond drilling, of course, a rotary outfit is required, which is rigged up over the hole as soon as the special casing has been set. The 5 to 10 feet of shale above the sand start a hole straight before it enters the sand. This type of drill takes a continuous core and losses in the sand are practically negligible in such fine-grained sandstones as the Bradford Third. The core barrels take 10 to 15 feet of core at a time. Water is circulated through the drill pipe and between the inner and outer tubes of the core barrel to the bit. The cuttings from the coring operation are thus washed to the surface around the outside of the core barrel and the drill pipe. Some loss of oil, no doubt, takes place at the cutting edge of the bit as it penetrates the sand owing to the tendency of the water under pressure to penetrate the sand just ahead of the bit, particularly in old fields, such as the Bradford, where the gas pressure is small. After the core is taken, the special casing is removed and the well is completed to full size with cable tools.

When cores are taken with the standard cable-tool outfit, a cable-tool core barrel is attached to the end of the stem of the standard string of tools in place of the ordinary bit as soon as it is desired to start coring. This barrel consists of two main parts: an outer drilling barrel and an inner core-retaining tube. The drilling barrel is composed of three parts: a drill-barrel head, a drill barrel, and a drill-barrel shoe which is faced with a special alloy, such as stellite. Coring is accomplished by alternately raising and dropping the drilling barrel which fits around the core-retaining tube, the motion being the same as for regular drilling, but somewhat slower. An annular channel is thus cut around a core which rises in the inner tube as coring proceeds. Care must be taken not to lift the core tube from the bottom of the hole after coring has started. From 4 to 7 feet of core can be taken at a time, but in most cases the best results are obtained by not exceeding five feet. The cores are not continuous, like diamond drill cores, but are in biscuit form because of wobbling of the barrel in the hole. The biscuits usually range from ½ to 2 inches in thickness and 2½ inches in diameter. As high as 95 and even 98 percent of cores are recovered at times if the drilling is carefully done. High percentages of core recovery are not as consistently obtained, however, as with the diamond drill. At least 20 feet of water should be in the hole while coring. Some loss of oil also occurs in coring with the cable-tool core barrel. Although the water in the hole is not under pressure, the breaking of the sand into biscuits exposes more surface for the oil to escape from and for water to penetrate the sand and displace the oil.

In the Bradford field, all diamond-drill coring has been done by contractors engaged solely in that type of drilling. The contractor furnishes the diamond-drilling outfit and the drillers. The operator usually sets the special casing required, furnishes the water supply, and two additional men for each tour to assist in lowering and raising the drill pipe.

In the cable-tool method of coring, the operator purchases his own cable-tool core barrel as it is not customary for the ordinary drilling contractors to add such equipment and take contracts for this type of work. The contractor receives a fixed sum per day for the time required to take the core, besides his regular footage charge, where the drilling is done on a contract basis. The operator pays for dressing the bits which have to be taken to a machine shop to be built up and refaced with stellite. Drilling is done by the regular crew, cable-tool drillers usually experiencing no difficulty in learning to operate the core barrel.

Diamond-drill cores are much more satisfactory but cost considerably more than cable-tool cores. In the Bradford field, where the sand is fine-grained and its general characteristics are already pretty well known, satisfactory results are usually obtained by the use of the cable-tool core barrel without resorting to diamond drilling.

Flood water. Water for flooding is now obtained largely from wells sunk in the alluvium of the major valleys. In the extreme southern part of the district, the Olean and Knapp sandstones which cap the broad divides are also a source of supply. The field on the divide between the Tunungwant drainage and the Allegheny as far south as Rew is served by the water-distributing system of the Reclamation Supply Corporation.

In drilling wells in the alluvium it is customary to use 12-inch casing. Water is brought to the surface either by air-lift or by electrically-driven deep-well centrifugal pumps. Centrifugal pumps are gradually replacing the air-lift. They operate more efficiently and consume less power.

Although many operators have introduced raw water, after allowing it to settle, into the intake wells, the tendency now is to install filtering and treating equipment. Not only is suspended matter removed but the hydrogen ion concentration and alkalinity of the water are so adjusted that corrosion is reduced to a minimum.

Triplex reciprocating pumps, direct or belt-driven by gas or Diesel engines or by electric motors, are mostly used to force the water through the water lines and into the sand. Centrifugal pumps directly connected to electric motors are being considered by some of the larger producers. Where the volume of water to be handled is sufficiently large and extremely high pressures are not required, the latter are probably the more economical type to install.

The main feeders of distributing lines are commonly 3-inch and 4-inch steel pipe and 2-inch pipe is used for lines to individual wells and for tubing in the intake wells. Pipe capable of withstanding pressures of 2,000 pounds per square inch is used. It is usually given a coat of bitumastic paint or cement on the inside and outside to protect it against corrosion. It is questionable, however, whether such a coating will last throughout the life of a flood. Water lines have to be buried about 30 inches in the Bradford district to keep them from freezing. The heads of intake wells are enclosed in boxes filled with sawdust.

With the pressures now used, it is necessary to cement the packer, which is run in on the 2-inch tubing, in place. Dougherty[90] has described the technique that has been developed for doing this. Where no gas "pay" has to be shut off, the packer normally is set 25 feet above the sand. After it has been set, an air test is applied. For this purpose, a small portable air compressor with a capacity of ten cubic feet per minute is used. If the packer is tight, it is possible to build up a pressure of 50 to 100 pounds on the sand by injecting air through the tubing. On the other hand, if it leaks, gas is soon forced out by the air and rolls out at the top of the well between the casing and the tubing. If this happens, the packer is moved either up or down the well, depending on which is the most desirable direction, until a satisfactory test is obtained.

A string of 1-inch tubing with special collars chamfered to permit easy sliding over the collars of the 2-inch is next set on the top of the packer. Four barrels of water are run in to wash off any oil that might be on the walls of the well. Ten sacks of cement mixed neat with 40 gallons of water are then let down. This ordinarily fills the space between the tubing and the wall for 60 feet. In running the cement it is customary to pour a pail of water down the tubing and then attach a length of steam hose to the tubing, the other end of which is immersed in the cement. The suction produced by the falling water pulls the cement from the mixing box without further handling. After enough time has elapsed for the cement to reach bottom, the 1-inch tubing is raised 100 feet and flushed out with several pails of water. A bumper is run over the 2-inch tubing on a sand line to make certain that the cement is the right distance above the packer. A second air test is made to assure that neither the tubing nor the packer has developed a leak during the cementing operation. After the 2-inch casing has been cemented in place, the 6¼-inch casing in the intake wells usually is pulled.

With a pressure of 1,000 pounds at the face of the sand and a spacing of 200 to 225 feet between intake and output wells, intake wells at the start will take anywhere from one to two and one-half and sometimes as high as four barrels of water per day per foot of oil-bearing sand, depending upon the permeability of the sand. With a constant pressure, the input rate declines most rapidly during the early stages of the flood and later much slower. According to Darcy's law, the velocity of flow through a sand is proportional to the pressure gradient. If the rate of input increases more rapidly than the rate at which the pressure gradient between input and output wells is increased, it is an indication that the pressure is too high.

Most operators place a meter on each intake well to record the amount of water entering the well. Meters have required considerable servicing to keep them in working order. Usually a strainer is placed in the line just ahead of the meter to keep material in suspension in the water from entering the meter.

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[90] H. K. Dougherty, Discussion of paper on oil well cementing methods: Pennsylvania State Coll. Min. Indust. Exper. Sta. Bull. 16, pp. 48-49, 1934.

It is seldom necessary to clean out intake wells if the water has been properly filtered and treated. In case an intake well does show a marked decline in capacity, this can be accomplished in one of several ways. The well is disconnected from the water line. The back pressure causes the water in the sand to flow back into the intake well thus flushing that part of the sand adjacent to the well. If the water has been admitted to the sand through two open couplings, as shown in Figure 106, a string of 1-inch tubing with a packer at the bottom is inserted inside the 2-inch and anchored midway between the two couplings, as shown in Figure 109. Water under pressure is then forced down the 1-inch tubing, out through the lower coupling into the space between the 2-inch and the face of the sand, back through the upper coupling, and to the surface through the annular space between the 1-inch and the 2-inch tubing. If perforated pipe has been used for admitting water to the sand instead of the two open couplings, the water in the well can be flowed to the surface by introducing compressed air by means of a ¾-inch line inside the 2-inch tubing to the bottom of the well. Perforated collars are placed in this line at about 250-foot intervals. Swabbing inside the 2-inch tubing has also been used to raise the water.

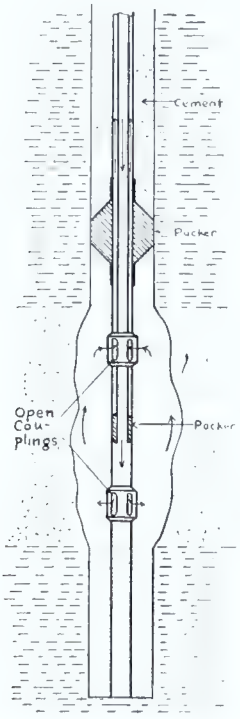

FIGURE 109. Diagram showing method of cleaning an intake well.

Producing wells are pumped through 2-inch tubing using ⅝-inch sucker rods. The bottom of the working barrel is usually placed opposite the bottom of the sand and a perforated tubing nipple extends about five feet below. It is customary to pump the face of the sand free of fluid at least once each day. If the well has showed any tendency to cave, a 4¼-inch perforated liner reaching about 25 feet above the top of the sand, is set on the bottom of the hole. The maximum rate of pumping usually is about 2.75 barrels of fluid per hour. By increasing the length of stroke and the number of strokes per minute, a rate of 4 barrels per hour is sometimes attained in wells that are producing an exceptionally large volume of fluid.

The separation of paraffin wax from the crude oil within the oil string of flood wells constitutes a troublesome production problem in the Bradford district. The paraffin accumulates mostly in the upper half of the tubing. On some properties it is necessary to pull the rods once every month to remove it and on most properties this has to be done at least once every three months. Two men with a tractor or three men with a team can usually pull two wells in a day. In parts of the district, gypsum collects on the bottom ball and seat of the pump, causing leakage and at times the formation of emulsions.

The multiple system of pumping wells is most common. The double eccentric band-wheel power is the most popular type. As many as 30 to 40 wells are frequently hooked up on one power, but usually only 16 to 20 are pumped at one time. In order to obtain the maximum efficiency, the load on the central power should be balanced. The load on the eccentrics should be so adjusted that the power requirements are practically constant throughout a complete revolution of the band-wheel. This necessitates a close study of the load factors imposed by the different wells and their directions from the power station. On account of the rugged nature of much of the terrain in the Bradford district, this frequently becomes a difficult problem. It has been discussed in a comprehensive paper by Nowels.[91] Powers are operated with gas engines if there is enough gas on the property. Otherwise Diesel engines or electric motors are used. Inasmuch as there now is a shortage of gas on many properties, single and double well electric pumping units are being installed by some operators instead of the central band-wheel powers.

The pumping jacks are mostly of the Oklahoma type, as shown in A, Plate 21. A single electric pumping unit is shown in B, Plate 21. In the field, the motor and driving mechanism are enclosed in a sheet iron case. This particular type has been assembled in the machine shop on the property at a cost of approximately $300. In the deeper wells, a single or double pipe or wooden pole derrick is usually erected at each well for pulling rods and tubing. In the shallower wells, a pulling machine with a small pole derrick is used. Most operators pump into a gauge tank set at the well. The water is separated from the oil in this tank, the former being drawn off onto the ground and the latter run into a stock tank from which it goes to the pipe line. Gas is taken off at the casing head and piped to the various power units on the property. The economic limit of a producing well depends upon such factors as the water output to oil ratio during the later stages of the flood and the prevailing price of crude oil at the time the flood reaches this stage. Under present conditions, most floods will have about reached their economic limit when the average daily output of oil per well over a period of one month has dropped to one-half barrel.

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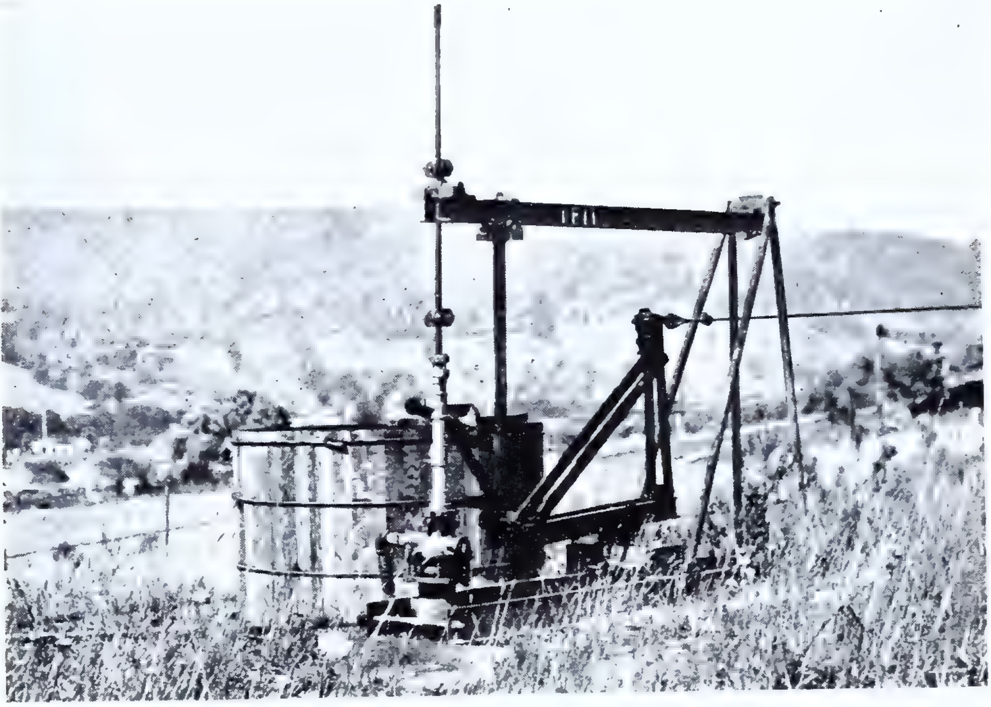
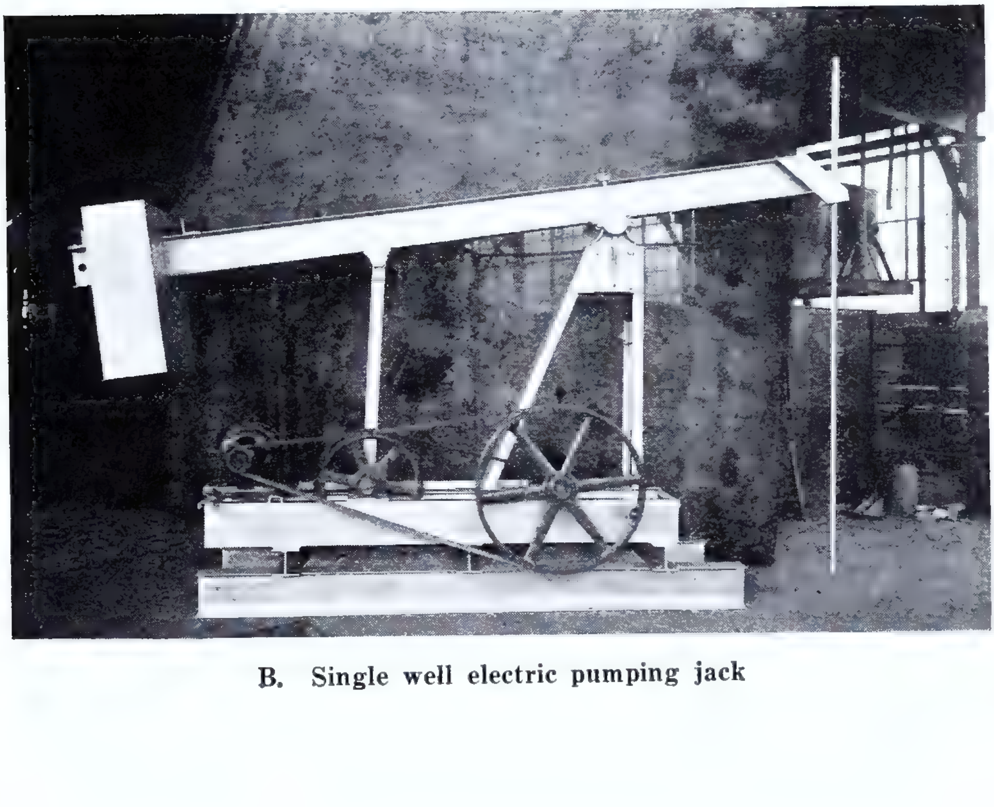
[91] K. B. Nowels, Surface and subsurface equipment loads of bandwheel powers: The Pennsylvania State College Min. Ind. Exper. Sta. Bull. 11, pp. 19-48, 1932.



A. Surface equipment of a producing well



B. Single well electric pumping jack

During the winter months, the pipe line companies require that the oil in the stock tanks be heated for pipe-line runs. The period during which this has to be done usually starts about the first of November and lasts until the first of April. One method of heating the oil is to place steam coils in the bottom of the tank. Little has described a number of different types of heaters that are used. [92]

As larger and larger areas of the Bradford field are being watered out, the amount of natural gas which accompanies the oil is steadily declining. On many properties there is no longer enough to operate the various power units during the life of a flood. In order to increase the amount of available gas, some operators now apply a vacuum, equivalent to five to ten inches of water, on all gas lines and also on the oil tanks. Gas engines are used for generating power wherever enough gas is available. Convertible Diesel engines are frequently installed and operated on gas during the earlier stages of a flood when gas is available and later changed over to operate on fuel oil. Some properties are now operated with electric power entirely. The Bradford Electric Company, which obtains its power from Niagara Falls, has power lines extending to practically all parts of the field. A few operators generate their own electric power, using either gas or Diesel engines to drive the generators.

One company operating in the Bradford field has been experimenting on a comparatively large scale in applying sufficient pressure in the intake wells to flow the producing wells. The seven-spot pattern has been used with a distance of 240 feet between intake and producing wells. The tubing in the producing as well as the intake wells had to be packed off and cemented above the producing sand to prevent the loss of oil through sands that overlie the Bradford Third. All old wells on the property which were not used as intake or producing wells had to be carefully plugged. Pressures of 1,900 to 2,200 pounds per square inch on the face of the sand in the intake wells are being applied. The producing wells are flowed for six hours at intervals of six hours through 2-inch tubing. Considerable paraffin separates out on the walls of the tubing, apparently more than when the wells are pumped. Usually the tubing does not become clogged entirely, as a sufficient pressure develops to dislodge the paraffin, but occasionally a well has to be cleaned by running a scraper in the tubing. To prevent the loss of oil to adjacent tracts due to the higher pressures obtained in the sand body, the boundary wells are pumped. During the earlier stages of the operation, probably on account of the presence of one or more old wells that had been overlooked or not properly plugged, two oil springs developed at a considerable distance from the property. Although complete data on total recovery for comparison are not yet available, the rate of production appears to be lower than when the wells are pumped.

Another company has experimented in flowing wells that were approaching the economic limit by pumping. In each instance the oil production showed a marked decline and there was an enormous increase in the water output.

The savings in cost of pumping equipment obtained by flowing the wells is in part offset by the increased cost of the pipe for water lines and tubing that has to be used to withstand the higher pressures and the cost of packing and cementing the tubing in the producing wells. Unless large tracts are flooded as a unit operation, there is a likelihood that considerable quantities of oil will be lost to adjacent tracts on account of the high pressure gradient that is established. With the intermittent operation of the producing wells, there is also some danger of back-flooding portions of the sand body.

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[92] Herman J. Little, The care and operation of small oil wells east of the Mississippi: Oil Properties, Amer. Petrol. Insti. Prod. Bull. 213, pp. 52-53, 1934.

On account of the intensive drilling campaign conducted during 1928 and 1929, production in the Bradford district increased more rapidly than the refiners of Pennsylvania grade crude oil were developing additional markets for their products. This condition and the effects of the world-wide depression that became felt at about the same time, necessitated the inauguration of a voluntary proration program, which was in effect between May 16, 1930 and October 15, 1931.

Several methods were used to curtail the production of floods already in operation. In a few instances the entire operation was shut down. The water was shut off from the intake wells and the producing wells were not pumped. Some operators either shut off the water completely or greatly reduced the pressure at which it was admitted into the intake wells, but continued to pump off the water from the producing wells. Others continued admitting water at normal or nearly normal pressures, but pumped off only water and the prorated amount of oil. The balance of the oil was allowed to head up in the producing wells. The back pressure thus developed proved quite effective not only in cutting down the rate of oil production but also in very appreciably reducing the water output.

Although no detailed figures were obtained, the writer was informed by those operators who had shut their properties down entirely, that the recoveries when operations were resumed were considerably below the amounts that had been anticipated. This method of curtailment probably resulted in the greatest loss in ultimate recovery.

A study of the production data of several properties, which were operated on a curtailed basis during 1930 and 1931, seems to indicate that the smallest losses in ultimate recovery occurred on those properties on which the admission of water at normal or nearly normal pressures was continued and the water was pumped off from the producing wells, curtailment of production being attained by removing only the prorated amount of oil and allowing the balance to head up in the wells. Where this method was applied to floods in the early stages of their productive cycle, little or no loss in ultimate recovery was apparent. Where the method was applied to floods that had reached that stage at which considerable amounts of water were already being produced with the oil, some loss in ultimate recovery probably occurred in most instances. At least the deferred production was recovered at an appreciably greater expense due to the low rate of production of the wells and the high water output to oil ratio.

Cost Data

The cost of producing a barrel of crude oil in the Bradford field by present day operating methods varies considerably from property to property. The most important factor is the amount of oil that can be recovered per acre from a particular tract. Since there is little difference in total development and operating costs between a poor and a good tract, the cost per barrel on a poor tract is high when compared with the cost on a good one. The cost of drilling the new wells required is the major item of expense in developing a tract. Hence the depth at which the oil sand is encountered is another important factor in determining cost per barrel. The cost is also dependent on sand conditions which affect the water input and water output to oil ratios. Accessibility to an adequate supply of water for flooding purposes is likewise important.

The above mentioned factors are intrinsic — they do not change with economic conditions. Besides, there are certain extrinsic factors, some of which have fluctuated widely during the past ten years, that must be taken into consideration in determining whether a particular tract can be profitably operated at the present time by intensive flooding methods. Most important among these is the average price that can be expected per barrel for crude oil during the life of the project. The price paid for acreage and whether the entire oil right or only a seven-eighths or other fractional working interest is involved are also major factors in determining cost per barrel to the producer. Prevailing wage scales and price levels of equipment and supplies are other important factors. Finally, the skill of the management usually plays an important role in determining whether a particular undertaking proves to be a financial success.

Total development and operating costs were obtained on two intensive type flooding operations, one in the Bradford and the other in the Richburg pool. The cost data given do not take into consideration the value of the acreage depleted by the operation or royalties. No allowance has been made for the salvage value of equipment and machinery. Taxes are included under operating expenses. The cost per barrel has been computed on the basis of the total production.

The Bradford project includes 63.8 acres. One hundred and twelve new wells of an average depth of 1,280 feet each were drilled on the tract at a cost of $1.00 per foot for the first 56 and $1.10 for the second. The water intake wells are spaced 215 feet apart, except where the pattern has had to be adjusted to boundaries. Water for flooding purposes is obtained on the property. It is not filtered. Production started in October 1929, but was drastically curtailed during 1930 and 1931. The recovery per acre on July 1, 1937 amounted to 5,690 barrels. This will be increased somewhat before the economic limit is reached as the average daily production per well was still 1.19 barrels. Development costs as of July 1, 1937 are given in Table 132 and operating costs by six-month periods are summarized in Table 133.

Table 132. Development costs of a 63.8 acre intensive water-flood in the Bradford Field.

Well and lease equipment	$127,431.29
Powers	14,702.27
Water plant	11,405.20
Development	190,219.61
Interest	22,675.25
Total	$366,433.62

Table 133. Operating costs of a 63.8 acre intensive water-flood in the Bradford Field.

Time	Total operating cost	Producing wells	Total oil production Barrels	Average daily oil production per well Barrels	Operating cost per barrel of oil produced
Oct. 1, 1929—April 1, 1930	$ 11,401	43	12,501	1.60	$ .912
April 1, 1930—Oct. 1, 1930	23,337	57	30,869	2.96	.756
Oct. 1, 1930—April 1, 1931	8,343	51	29,404	3.17	.284
April 1, 1931—Oct. 1, 1931	7,904	50	28,328	3.10	.279
Oct. 1, 1931—April 1, 1932	6,720	50	57,298	6.26	.117
April 1, 1932—Oct. 1, 1932	6,574	50	41,331	4.52	.159
Oct. 1, 1932—April 1, 1933	5,837	50	29,040	3.17	.201
April 1, 1933—Oct. 1, 1933	8,773	50	30,564	3.34	.287
Oct. 1, 1933—April 1, 1934	7,102	50	18,964	2.08	.375
April 1, 1934—Oct. 1, 1934	4,778	50	14,500	1.58	.329
Oct. 1, 1934—April 1, 1935	3,941	51	13,550	1.46	.298
April 1, 1935—Oct. 1, 1935	5,178	54	14,419	1.46	.359
Oct. 1, 1935—April 1, 1936	5,634	54	12,576	1.27	.448
April 1, 1936—Oct. 1, 1936	6,324	54	12,005	1.21	.527
Oct. 1, 1936—April 1, 1937	4,634	54	11,849	1.21	.391
April 1, 1937—July 1, 1937	2,824	54	5,847	1.19	.483
Total	$119,304		363,045		$ .329

Development cost, per barrel	$1.009
Operating cost, per barrel	.329
Total development and operating cost, per barrel	$1.338

The Richburg project includes 28.29 acres. Forty-nine new wells of an average depth of 1,236 feet each were drilled on this tract at a cost of 90 cents per foot. In addition, there are six intake wells along the boundaries that were paid for by the owners of the adjacent properties. The water intake wells are spaced 240 feet apart, except where the pattern had to be adjusted to the boundaries. The property is equipped with two pumping powers. Water for flooding is obtained on the tract. It is raised by air-lift and allowed to settle in a large tank, but it is not filtered. Two triplex pump units, each 2½ x 6 inches, are used to force the water into the sand. The air compressor, triplex pumps, and one of the powers are operated by a 40-horsepower gas engine, and the other power by a 25-horsepower engine. Production started in October 1928. It was curtailed during 1930 and 1931. Total ultimate recovery per acre, it is estimated, will be about 8,000 barrels. The development costs have been tabulated in Table 134.

Operating costs and production data for the Richburg project were available to July 1, 1935. The projected decline curve indicates that the average daily oil production per well will have dropped to one-half barrel by about the end of 1937. The probable production between July 1, 1935 and December 31, 1937 has been calculated from this curve. Operating costs after July 1, 1935 have been estimated at $2,090.00 per six months, the amount that they were during the last six months for which the actual figures were obtained. The operating costs by years are summarized in Table 135.

Table 134. Development costs of a 28.29-acre intensive water-flood in the Richburg pool, Allegany County, New York.

Well and lease equipment		$ 31,702.09
Tubing and pipe	$22,298.12	
General supplies, including pumping jacks, fittings, small pipe, etc.	7,527.66	
Pull rods	393.80	
Sucker rods	1,482.51	
Water plant and powers		20,034.84
Development		72,599.72
Drilling	$55,076.13	
Shooting	11,415.75	
Labor	4,500.29	
Teaming	1,210.70	
Freight and express	307.10	
Surveying	67.75	
Legal expense	22.00	
Total		$124,336.65

Table 135. Operating costs of a 28.29-acre intensive water-flood in the Richburg pool, Allegany County, New York.

Time	Total operating cost	Producing wells	Total oil production, bbls.	Av. daily oil production per well, bbls.	Operating cost per bbl. of oil produced Dollars
Actual costs					
Last ¼ of 1928	$ 1,327.35	30	2,981	1.08	.445
1929	4,854.22	30	55,955	5.11	.087
1930	5,648.50	32	42,912	3.67	.131
1931	9,440.33	33	24,889	2.08	.379
1932	6,114.26	33	25,782	2.13	.237
1933	3,897.44	33	21,824	1.81	.179
1934	4,514.60	33	18,880	1.57	.239
First ½ of 1935	2,090.14	33	7,760	1.30	.269
Estimated costs					
Second ½ of 1935	2,090.00	33	7,100	1.17	.294
1936	4,180.00	33	11,230	.93	.372
1937	4,180.00	33	7,370	.61	.567
Total	$48,336.84		226,683		.213

Development cost per barrel	$ .549
Operating cost per barrel	.213
Total development and operating cost per barrel	$ .762

In Table 136 are given the operating costs for a period of six months of a third property in the Bradford field. It will be noted that the cost per barrel of oil produced corresponds rather closely to that of the first property, shown in Table 133, when its wells had reached the same stage in their production history.

Table 136. Operating costs of a property in the Bradford Field during the second half of 1933.

Number of band-wheel powers	3
Number of producing wells	69
Oil output—barrels	14,033
Water output—barrels	138,287
Average daily oil production per well—barrels	1.11
Average daily water output per well—barrels	10.89
Operating costs:	
Pumping labor	$2,433.41
Power repairs and maintenance	265.81
Well and rod line maintenance, including pulling, etc.	
Labor	754.06
Materials	587.00
General expenses, including cost of water for flooding purposes, electric light and power, lubricating oil, supplies, compensation insurance, etc.	2,846.73
Taxes	600.64
Total operating costs	$7,487.65
Operating cost per barrel of oil produced	.534

The production costs for two properties in the Bradford field over a period of nine years, during which circle floods were operated on them, are given in Tables 137 and 138. No allowance has been made for the value of the acreage depleted or for royalties. Expenditures for operation and for maintenance during the last year have been classified with reference to their nature and itemized in Tables 139 and 140, respectively. Costs per barrel of oil produced were appreciably higher than they are under the intensive method of flooding now in use.

Table 137. Circle flood production costs on a 500-acre tract in the northern part of the Bradford Field.

Year	Producing wells	Average daily oil production per well, barrels	Oil produced, barrels	Operating costs	Operating cost per barrel oil produced	Maintenance cost
1920	103	.24	9,881	$ 10,273.73	$1.040	$ 9,309.58
1921	107	.29	11,418	10,190.23	.892	11,793.34
1922	115	.28	11,922	8,817.62	.740	8,939.98
1923	122	.36	16,072	10,270.85	.639	11,629.74
1924	124	.30	13,663	10,721.99	.785	11,802.41
1925	124	.44	20,134	12,289.10	.610	24,597.13
1926	136	.47	23,485	16,093.90	.685	23,017.79
1927	150	.50	27,144	18,742.78	.691	25,801.10
1928	165	.46	27,585	20,023.38	.733	25,021.46
Total			161,304	$117,423.58	$ .728	$151,912.53

Year	Maintenance cost per barrel oil produced	Cost of additions	Cost of additions per barrel oil produced	Total cost	Total cost per barrel oil produced	Number of wells drilled and revived	Number of wells abandoned
1920	.942	$ 5,347.45	$ .541	$ 24,930.76	$2.523	8	4
1921	1.033	3,069.86	.269	25,053.43	2.194	8	0
1922	.750	4,577.25	.384	22,334.85	1.873	9	2
1923	.724	4,260.49	.266	26,161.08	1.628	10	8
1924	.864	3,645.43	.267	26,169.83	1.915	8	8
1925	1.221	12,397.75	.616	49,283.98	2.448	17	5
1926	.980	7,427.71	.317	46,539.40	1.982	16	2
1927	.951	14,983.43	.552	59,527.31	2.193	21	6
1928	.910	4,906.52	.178	49,951.36	1.811	20	16
Total	$ .942	$60,615.89	$ .376	$329,952.00	$2.046		

Table 138. Circle flood production costs on 300-acre tract in the northeastern part of the Bradford Field.

Year	Producing wells	Average daily oil production per well, barrels	Oil produced, barrels	Operating cost	Operating cost per barrel oil produced	Maintenance cost
1920	62	.82	18,618	$ 15,618.10	$ .839	$ 24,511.98
1921	69	.77	19,485	15,390.44	.790	14,844.11
1922	73	.49	13,071	14,908.04	1.141	14,138.11
1923	80	.43	12,422	16,260.78	1.310	14,347.26
1924	81	.65	19,318	17,009.70	.881	13,426.45
1925	80	.74	21,643	16,229.69	.750	13,324.75
1926	84	.64	19,686	19,918.77	1.012	24,116.39
1927	95	.67	23,334	18,423.51	.790	20,142.18
1928	96	.90	31,774	22,006.79	.693	28,639.96
Total			179,351	$155,765.82	$ .869	$167,491.19

Year	Maintenance cost per barrel oil produced	Cost of additions	Cost of additions per barrel oil produced	Total cost	Total cost per barrel oil produced	Number of wells drilled and revived	Number of wells abandoned
1920	$1.317	$11,758.49	$ .632	$ 51,888.57	$2.787	12	5
1921	.762	5,930.77	.304	36,165.32	1.856	6	2
1922	1.082	5,272.74	.403	34,318.89	2.683	9	2
1923	1.155	5,467.96	.446	36,076.00	2.904	8	7
1924	.695	1,210.12	.063	31,646.27	1.631	9	10
1925	.616	3,739.89	.107	33,294.33	1.538	7	3
1936	1.225	12,343.06	.627	56,378.22	2.864	14	3
1927	.863	7,294.00	.313	45,859.69	1.965	13	12
1928	.914	11,353.53	.361	62,000.28	1.951	22	7
Total	$ .934	$64,370.56	$ .358	$387,627.57	$2.161		

Table 139. Itemized statement of operating costs by circle flood method during 1928 of two properties in the Bradford Field.

	500-acre tract	300-acre tract
Oil produced, barrels	27,585	31,774
Number of producing wells	165	96
Average daily production per well, barrels	.46	.90
Operating costs:		
Labor	$ 7,439.70	$ 8,604.87
Supplies	2,612.17	2,444.53
Lubricants	224.95	177.71
Team	781.83	1,380.00
Tractor	324.07	
Cleaning out expense:		
Labor	1,356.26	1,485.50
Team	210.68	50.00
Supplies	603.84	
General expense	1,032.18	1,046.60
Office expense	3,220.69	3,550.22
Auto expense	459.66	263.88
Insurance	307.54	344.27
Taxes	1,274.52	2,217.40
Miscellaneous	175.29	441.81
Total operating costs	$20,023.38	$22,006.79
Operating cost per barrel	.733	.693

Table 140. Itemized statement of maintenance costs by circle flood method during 1928 of two properties in the Bradford Field.

	500-acre tract	300-acre tract
Oil produced, barrels	27,585	31,774
Number of producing wells	165	96
Average daily production per well, barrels	.46	.90
Number of wells drilled and revived	20	22
Number of wells abandoned	16	7
Maintenance costs:		
Labor	$ 923.33	$ 1,217.90
Supplies	3,018.90	2,754.94
Team	380.32	570.00
Cost of operating company-owned drilling tools:		
Labor	3,191.39	
Team	258.68	
Supplies	539.81	
Drilling contractor	14,289.09	21,061.50
Shooting	2,419.94	3,035.62
Total maintenance costs	$25,021.46	$28,639.96
Maintenance cost per barrel	.910	.914

The drilling and equipping of the intake and producing wells constitute the major items of expense in developing an intensive flood project. Actual costs of several intake and producing wells are given in Table 141. As shown, the costs were appreciably lower during 1933 and 1934 than they were in 1929. The cost of the surface equipment of a typical producing well in 1929 is given in Table 142.

Table 141. Cost of intake and producing wells.

Type of well	Water intake*	Producing well	Water intake	Producing well
Depth, feet	1,881	1,775	1,847	1,735
Year drilled	1929	1929	1933	1934
Clearing location	$ 9.60	$ 9.60	$14.70	$16.20
Hauling pipe	15.00	15.00	15.00	15.00
Drilling	1881 ft. @ $1.00 $1881.00	1775 ft. @ $1.00 $1775.00	1847 ft. @ .80 $1477.60	1735 ft. @ .80 $1388.00
Shooting	80 qts. $133.00	$192.50	100 qts. $170.00	$145.00
8¼-inch casing	32 ft. @ .849 $27.16	38 ft. @ .849 $32.25	61 ft. @ .776 $47.32	41 ft. @ .826 $33.88
6¼-inch casing	18 ft. @ .631 $11.35	280 ft. @ .631 $176.57	Pulled	275 ft. @ .594 $163.40
2-inch tubing	1811 ft. 3 in. @ .182 $305.92	1753 ft. @ .182 $318.52	1753 ft. 7 in. @ .175 $307.40	1711 ft. @ .175 $299.94
2-inch perforated tubing	63 ft. 7 in. $11.55		98 ft. 2 in. @ .168 $16.46	
6¼-inch by 2 feet R & L nipple and collar	3.00			
2-inch R & L brass nipple and collar	4.00		1.62	
2-inch O.W.S. water valve	20.00			
Heinz cap packer	3.50			
Macksburg or Bradford flood packer	13.05		10.90	
Wood plugs			3.00	
2-inch tubing clamp	2.50			
Cement and sand	26.00		5.70	
Meter box and fittings	57.85		43.00	
Sucker rods		1753 ft. @ .056 $98.17		1705 ft. @ .078 $132.99
Well equipment		$34.12		$56.90
4¼-inch liner		173 ft. @ .398 $68.92		
Total	$2,524.48	$2,720.65	2,112.70	$2,251.31

*This well was equipped to take water either from surface or subsurface.

Table 142. Cost of surface equipment of a producing well in 1929.

1	Pumping jack	$ 40.00
386	feet pull rods	25.05
17	Support posts	17.00
1	Work stroke post installation	19.00
1	Rod line hold down	4.50
1	Rod line hold over	7.00
1	Shear pole derrick	60.00
137	feet gas line	30.00
130	feet oil line	28.46
1	Tank	41.00
		$ 272.01

The cost of the water used for flooding is an appreciable item of expense during the life of an intensive flood. Costs during 1933 for two properties in the Bradford field which are so located that adequate supplies of water are available from alluvial-filled valleys are given in Table 143. Water lines to wells have to be buried about 2½ feet to keep them from freezing. The cost of installing a typical water line in 1933 is given in Table 144.

Table 143. Cost of water for flooding on two properties in Bradford District during 1933.

One well on each property	Property A Centrifugal pump Unfiltered water	Property B Air-lift Filtered water
Cost of water plant	$25,513.69	$33,454.18
Operating expenses 1933	3,396.22	4,862.18
Depreciation (7 years)	3,644.81	4,779.17
Total expense	$ 7,041.03	$ 9,641.35
Barrels of water pumped	668,632	627,794
Cost per barrel	$0.0105	$0.0154

Table 144. Cost of ditching, laying and back-filling 1,850 feet of 4-inch water line in Bradford Field in 1933.

Ditching 8c and back-filling 1c per foot	$ 166.50
Labor laying pipe	313.63
Tractor	24.28
Truck	14.14
Total	$ 518.55

Cost per foot, 28 cents

Use of Chemicals as Flooding Agents

During 1925 and 1926 considerable interest was aroused among operators in the Bradford field in regard to the possibility of appreciably increasing the recovery of oil by adding certain chemicals such as sodium carbonate to the water used in flooding. Several investigators had reported that certain water-soluble salts, when dissolved in the flood water, had an important effect in releasing oil held by adhesion on the sand grains.[93]

Fyleman,[94] who patented the process of using dilute sodium carbonate solutions to separate oil or bitumen from rock, following Reinders,[95] attributed the tendency of sodium carbonate solutions to displace oil from the grains of oil-bearing sands and sandstones to a rearrangement of the interfacial tension relationships between the water, oil, and sand grains in which the interfacial tension between the oil and the sand grains becomes greater than the sum of the interfacial tension between the water and the sand grains and that between the oil and the water. He advocated the use of an aqueous solution of low surface tension, one that froths readily, such as a solution of an alkali soap, of the alkali salt of a weak organic acid, or of saponin. As most bitumens and many crude petroleums contain small amounts of compounds of weakly acid character, he thought that it is frequently sufficient to add to the water a very small amount of alkali such as soda ash.

Nutting suggested that an attraction exists between the silica (SiO_2) of the sand grains and the hydrogen ions of the water which results in the formation of a surface layer of siloxyl ($SiOOH$) radicals on the former. These radicals are acidic in character and possess one free bond by means of which they can unite with some other substance. A reaction occurs between the siloxyl radicals and the basic constituents of the oil so that over the surface of the sand grains a chemical combination of the oil with the silica takes place, which is quite stable. On account of the formation of this compound, pure water is not very efficient in displacing the oil from the grains. If, however, some alkali salt is added, the oil is much more completely displaced; the strong base displacing the weaker one from the acidic siloxyl radical.

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[93] Ernest Fyleman, The separation of adherent oil or bitumen from rock: Jour. Soc. of Chem. Ind., vol. XLI, pp. 14T-16T, 1922.
P. G. Nutting, Chemical problems in the water driving of petroleum from oil sands: Indus. and Eng. Chem., vol. 17, pp. 1035-1036, 1925.
R. C. Beckstrom and F. M. Van Tuyl, The effect of flooding oil sands with alkaline solutions: Bull. Amer. Assoc. Petroleum Geologists, pp. 223-235, 1927.

[94] English Patent, 163519 (1920), Canadian Patent, 203676 (1920).

[95] W. Reinders, Die verteilung eines suspendierten pulvers oder eines kolloid gelosten stoffes zwischen zwei Lösungsmitteln. Kolloid-Zeitschrift, Band XIII, pp. 235-236, 1913.

Uren[96] attributed the effect of the soda ash primarily to its influence on the interfacial tension between the water and the oil, and on that between the water and the silica. He believes that the soda solution reacts chemically with both the silica of the sand grains and the oil. Sodium carbonate in water solution hydrolyses to form sodium hydroxide and the latter reacts with silica according to the following equations:

$$Na_2CO_3 + H_2O = NaOH + NaHCO_3$$
$$NaOH + SiO_2 = NaHSiO_3$$

Due to this reaction, the interfacial tension between the water and the sand grains becomes very low. Uren also found that the interfacial tension between crude petroleum and a water solution of sodium carbonate is low, 6 dynes as compared with 18 dynes for pure water, when measured in the same way. This is probably due to the action of the sodium hydroxide on certain acid constituents of the oil.

Bartell and Miller [97] found that alkaline solutions such as sodium carbonate greatly reduce the interfacial tension of the water-crude oil interface, whereas they increase slightly the water-benzene interfacial tension. This would indicate that the alkaline substances react with some constituent of the crude oil, so that a compound is formed which is highly absorbed at the water-crude oil interface, thus greatly decreasing the interfacial tension. They found, however, that this reaction between the oil and alkali does not have an appreciable effect upon the displacement of oil from the sand, since the alkaline solutions appear to displace the benzene from the sand just as effectively as they do the oil. They concluded, therefore, that the increased effectiveness of the alkaline solution in displacing liquids from silica is due to a reaction between the silica and the aqueous solution. Either the base reacts chemically with the silica or is highly absorbed by it. The factor determining the efficiency of flooding agents then appears to be associated with the aqueous solution—silica portion of the system, which is in accordance with Nutting's views.

In contrast to the high recoveries obtained by the investigators already cited, who experimented largely with unconsolidated sands, Barnes[98] found by laboratory experiments that solutions of sodium carbonate, sodium silicate, and sodium hydroxide are no more effective than water as recovery agents in a forced drive through tightly consolidated Pennsylvania oil-bearing sandstones. Sodium soap solutions are slightly better than water, but cost more and present difficulties in operation.

Nutting[99] proposed that a concentrated solution of sodium carbonate be introduced for a time in each intake well until a bank of solution had accumulated behind the oil bank, and that ordinary water be then used to drive the soda solution and the oil toward the recovery well. He recommended that a sufficient quantity of solution, containing about 50 pounds of soda ash per barrel of water, be used to form a wall of solution at least a foot thick against the oil. For a sand 30 feet thick, he estimated that 200 barrels would be required. More than this he considered unnecessary as he thought that the soda solution would remain at the front of the advancing water until the recovery well, 150 feet or so away, was reached. The amount of calcium carbonate likely to be precipitated by the reaction between the sodium carbonate and the calcium chloride that occurs in the small amounts of connate water present in the sand, he thought, would not cause any preceptible clogging of the pores. However, if an oil sand has been watered out by a connate water containing calcium chloride, attempts to redrive it with soda solution would probably not be successful.

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[96] Lester C. Uren. Increasing oil recovery by flooding: National Petroleum News, vol. XIX, pages 53-59, August 3, 1927.

[97] F. E. Bartell and F. L. Miller, Displacement of crude oil and benzene from silica by aqueous solutions: Indus. and Eng. Chem., vol. 24, pp. 335-338, 1932.

[98] K. B. Barnes. Preliminary experiments in oil recovery: The Pennsylvania State College Min. Ind. Exper. Sta. Bull. 11, pp. 84-97, 1932.

[99] P. G. Nutting, Soda process for petroleum recovery: Oil and Gas Jour. March 31, 1927.

Uren[100] has pointed out that the soda solution would be used up in wetting the sand in the vicinity of the intake well unless it is assumed that it is continually replaced by water from behind. At least it would probably be much diluted by water from behind as the fresh water would take up only a part of the alkaline reagent by diffusion. In the Bradford field the precipitation of calcium carbonate by the reaction of the sodium carbonate with the calcium chloride in the connate water that is present in small amounts in the sand would also tend to use up the reagent.

During 1925 and 1926, probably as much as $60,000 was spent in the Bradford field on tests with soda ash in which the procedure recommended by Nutting was followed. At that time, with very few exceptions, subsurface water was being used for flooding and the circle and line types of floods were still in vogue. Unfortunately most of the tests were conducted in such a manner that direct comparison of the results obtained with and without the use of soda ash under exactly similar conditions were not possible. However, in no instance where the soda ash was used, was the recovery greater[1] than what would have been anticipated without its use. On the other hand, only one case came to the writer's attention in which it was reported that the use of the soda ash resulted in clogging the pores of the sand by precipitating calcium carbonate in them, thereby reducing the recovery of oil.

On the property in question, two line floods were started at about the same time. Sodium carbonate solution was introduced into the intake wells of one line, hereafter called Flood A, following the procedure recommended by Nutting, but not into those of the other line, designated as Flood B. The south end of Flood A was 2,000 feet northwest of the west end of Flood B. The distance between the rows of wells in each flood was 110 feet and the wells were 210 feet apart in the rows, making the distance from water intake to oil well approximately 152 feet. The above distances were varied slightly to adjust the lines to the boundaries of the property so that, while, on the basis of the number of producing wells, Flood A equalled 82 percent of the area covered by Flood B, the actual area was only 78 percent of that of Flood B. A row of oil wells was drilled on each side of the row of intake wells in both floods.

The intake wells of Flood A were completed and subsurface water let in between August 1925 and August 1926. The depth of the sand was such that the maximum pressure possible by hydrostatic head was 750 pounds per square inch. The first oil wells were completed in July 1926. Because Flood A was on a divide, the supply of subsurface water was inadequate. After October 1926 water from a small stream was pumped into the intake wells under just sufficient head to reach the top of the highest well. This water was not filtered.

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[1] Lester C. Uren, Op. cit.

The intake wells of Flood B were completed and subsurface water let in to them between March and August, 1925. The depth of the sand was such that the maximum pressure possible by hydrostatic head was 700 pounds per square inch. The first oil wells were completed in September 1925. Surface water from the same stream as that which supplied Flood A was first introduced into the intake wells in November 1928. The change from subsurface to surface water had very little effect on the production of the first row of oil wells on either side of the intake wells. They had by that time declined to an average daily production of only 0.54 barrels per well.

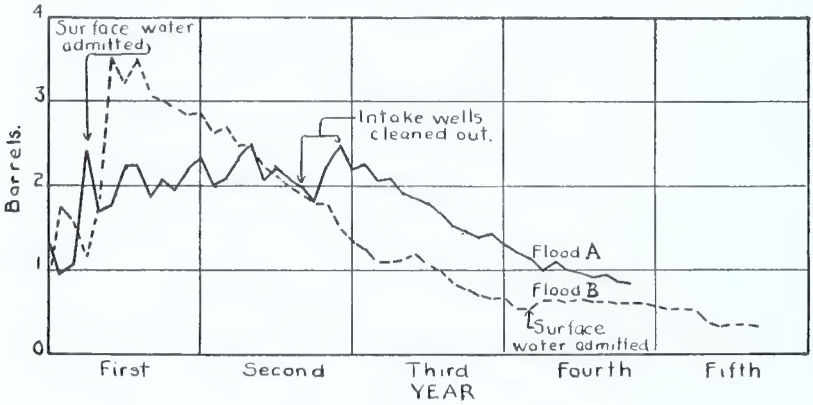

FIGURE 110. **Curves showing average daily oil production per well by months of two line floods.**

The average daily oil production per well and the total cumulative production of the two floods by months is given in Table 145. The average daily oil production per well is also shown graphically in Figure 110. It will be noted that the two floods behaved quite differently. Flood A did not reach a peak until 17 months had elapsed and then the average daily production per well was only 2.49 barrels. In contrast, Flood B reached its peak after eight months with an average daily production per well of 3.48 barrels. This led to the conclusion that the introduction of the sodium carbonate solution into the intake wells of Flood A had resulted in clogging the pores of the sand. During the spring of 1928, therefore, these intake wells were shot a second time and cleaned out. This resulted in an almost immediate increase in production, as shown in Figure 110, and thereafter the performance of Flood A was noticeably better than that of Flood B.

Table 145. Average daily oil production per well and total cumulative production of two line floods, by months, in barrels.

	Flood A Intake wells treated with soda ash			**Flood B** Intake wells not treated		
Month	Daily	Number of wells	Cumulative	Daily	Number of wells	Cumulative
1	1.36	2	84	.95	1	29
2	.95	4	202	1.73	3	190
3	1.05	5	360	1.56	5	424
4	2.43	8	963	1.14	8	708
5	1.71	9	1,424	1.81	10	1,268
6	1.78	10	1,976	3.52	9	2,155
7	2.24	12	1,808	3.19	16	3,739
8	2.25	14	2,689	3.48	19	5,722
9	1.86	16	3,613	3.06	21	7,714
10	2.08	17	4,673	2.99	22	9,685
11	1.95	17	5,699	2.91	22	11,669
12	2.21	18	6,890	2.83	22	13,602
13	2.33	18	8,191	2.86	22	15,491
14	2.00	18	9,310	2.62	22	17,275
15	2.09	18	10,439	2.70	22	18,959
16	2.35	18	11,749	2.47	22	20,646
17	2.49	18	13,095	2.49	22	22,342
18	2.07	18	14,251	2.22	22	23,711
19	2.22	18	15,491	2.12	22	25,154
20	2.07	18	16,570	1.99	22	26,471
21	1.98	18	17,678	1.90	22	27,768
22	1.83	18	18,668	1.78	22	28,946
23	2.26	18	19,928	1.80	22	30,129
24	2.48	18	21,267	1.51	22	31,160
25	2.20	18	22,673	1.34	22	32,042
26	2.26	18	23,932	1.25	22	32,892
27	2.06	18	25,046	1.11	22	33,621
28	2.09	18	26,210	1.09	21	34,335
29	1.91	18	27,240	1.13	21	35,070
30	1.86	18	28,280	1.19	21	35,771
31	1.79	18	29,282	1.07	21	36,468
32	1.67	18	30,123	.99	21	37,082
33	1.51	18	30,963	.84	21	37,630
34	1.46	18	31,752	.78	21	38,123
35	1.39	18	32,526	.69	20	38,552
36	1.43	18	33,248	.67	21	38,990
37	1.29	18	33,970	.67	21	39,415
38	1.22	18	34,651	.54	20	39,747
39	1.15	18	35,274	.54	21	40,085
40	1.10	18	35,887	.64	21	40,504
41	1.10	18	36,482	.64	20	40,899
42	1.09	18	37,093	.62	21	41,264
43	.97	18	37,636	.65	21	41,690
44	.92	18	38,098	.62	21	42,082
45	.95	18	38,630	.62	21	42,483
46	.87	18	39,100	.60	21	42,862
47	.84	18	39,571	.61	21	43,262
48				.59	20	43,626
49				.57	20	43,970
50				.53	20	44,307
51				.54	20	44,632
52				.53	20	44,958
53				.38	20	45,191
54				.33	20	45,376
55				.36	20	45,597
56				.33	20	46,020
57				.36	20	45,813

At the end of 47 months the total production from Flood A amounted to 39,571 barrels and of Flood B to 43,262 barrels. Since Flood A included an area only 78 percent as large as that covered by Flood B, the recovery obtained from it, computed on an acreage basis, was the greater of the two by an appreciable margin. Also at the end of that period, the average daily production per well for Flood A was still 0.84 barrels as compared with 0.61 barrels for Flood B. The average total thickness of the sand body under the area covered by Flood A, according to the drillers' records, was 63 feet as compared with 42 feet for Flood B. Sufficient data were not available to determine the average thickness of oil-bearing sandstone underneath the two areas, but indications were that the percentage of the total thickness was probably somewhat lower in the area covered by Flood A than in that covered by Flood B.

Some of the fragments of sandstone recovered in cleaning the intake wells of Flood A showed appreciable quantities of calcite ($CaCO_3$) between the quartz grains when examined in thin section under a polarizing microscope. This calcite, however, had the same texture as calcite observed in certain layers of the Bradford Third sand in other parts of the field where no sodium carbonate solutions had had access to the sand. The writer thinks, therefore, that its presence was not necessarily due to precipitation by the sodium carbonate solutions.

The fact that shooting and cleaning out the intake wells brought about an almost immediate increase in production indicates that whatever clogging of the pores had occurred must have been confined to the immediate vicinity of the intake wells. The shooting and cleaning out of the wells could not have had any effect on calcium carbonate precipitated in the pores of the sand more than a few feet back from the walls of the intake wells. It is possible that the concentration of sodium carbonate solution used was too high and some of the reagent precipitated in the pores of the sand immediately adjacent to the walls of the intake wells, particularly if the solution was still warm when introduced. Also sediment in the creek water, which was not filtered, may have partially mudded off the walls of the sand. In view of the above facts, the writer thinks that the behaviour of Flood A furnished no evidence that the introduction of the sodium carbonate solution resulted in any appreciable clogging of the pores of the sandstone by the precipitation of calcium carbonate in them.

Chemicals are not being added to the water used for flooding in the Bradford field at the present time to aid in the removal of the absorbed oil from the sand grains. On account of the manner in which the field tests with sodium carbonate were conducted, however, the results obtained can hardly be interpreted as proving conclusively that sodium carbonate or possibly other flooding agents would not be effective in increasing the recovery of oil if administered in a somewhat different manner from that originally suggested by Nutting. The problem is one that merits further investigation.

AIR AND GAS DRIVES

From 1925 to 1928 inclusive, several experiments on a fairly large scale were underway in the Bradford district to determine the possibilities of employing compressed air to increase production, but all these have now been discontinued. A few operators introduced natural gas into an occasional well or two on their properties in an attempt to bring about a combined gas and water drive on a producing well, but such practice was followed only on a very limited scale because of the small volume of natural gas available for such purposes. The amount of oil produced in this way was almost negligible when compared to the total output of the field.

There are several reasons why the air drive has not been a success in the Bradford field. The most important undoubtedly is the character of the sand itself. In much of the field the sand is so fine and so low in permeability that pressures considerably greater than 400 pounds are necessary to produce an appreciable increase in production. Even where a reasonable degree of success was attained by the use of compressed air, the results in terms of increased production per acre were so small when compared to what can be obtained by water-flooding that, in spite of the much higher development costs of the latter method, the opportunities for a profitable return on the capital invested are much better. This is particularly applicable to properties purchased at the high prices that prevailed in recent years.

Haskell[2] has described what has probably been the most successful air-drive operation in the Bradford field, as follows:

"The area consists of 41 wells, drilled from 1885 to 1895, situated on 266 acres. This gives a well spacing of one well to 6.48 acres. Pressure was first applied to this area in October, 1925 through nine intake wells, whose daily input averages 68,600 cu. ft. of air at 300 lb. pressure. The action of the pressure was relatively quick, in many cases bringing wells having average normal production of 0.25 bbl. per day up to as high as 12 bbl. per day in less than two months. While all of the 41 wells show some effects from pressure, only 22 of them have gained the full effects of it. The production from these wells was 3,474 bbl. in 1929, 15,697 bbl. in 1926, and 18,524 bbl. in 1927. The 1928 production is expected to be only slightly lower than that shown by the 1927 figures. (This was 16,418 bbl.) Water-flooding has played no part in this recovery and it is interesting to note that only one well has been drilled in this area since pressure was applied."

Taking the 1925 production as the natural production of the wells involved, an analysis of the above figures shows that this was increased 4.5 times during the first year that the air-drive was in operation, 5.3 times during the second year, and 4.7 times during the third year. The air-drive was discontinued at the end of 1928. Inasmuch as nearly 10,000 bbl. of the 50,639 recovered from the 266 acres during the 3 years that the air-drive was in operation can be attributed to natural production, the increased recovery for the 3 years due to the air-drive amounted to only a little over 150 bbl. per acre.

During 1929, several cores were taken in the area in which the air-drive described above proved effective. In each case a condition similar to that shown in cores 18 and 19 of Figure 13 and Plate 18 was revealed. In cores 18 and 19 the sand is seen to consist of three parts. In core 18 the upper part, 13.64 feet thick, has an average porosity of 14.1 percent; the middle a so-called "loose-streak," 9.97 feet thick, an average of 22.8 percent; and the lower part, 18.18 feet thick, an average of 14.7 percent. In core 19 the upper part, 18.26 feet thick, has an average porosity of 12.7 percent; the middle 7.44 feet thick, an average of 23.3 percent; and the lower part 18.11 feet thick, an average of 14.9 percent. Three samples tested from the upper part of core 19 had an average oil content of 43 per cent by volume of the total pore space; one sample from the middle 39 percent; and two samples from the lower part an average of 50 percent. On the basis of these tests there are present 7,700 barrels of oil per acre in the upper, 5,200 barrels in the middle and 10,500 barrels in the lower part—a total of 23,400 barrels for the entire sand body.

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[2] R. M. Haskell, Pressure recovery in eastern field: Oil and Gas Jour., p. 32, May 24, 1928.

Outside the 266 acres mentioned, no appreciable increases in oil production by the air drive, even when the pressure was raised to 475 pounds, were observed on adjacent parts of the same property. None of the numerous cores taken in these adjacent areas show the middle so-called "loose-streak." Core 20, Figure 14, is typical of these areas. There can be no doubt that on this particular property practically the entire increase in production due to the air-drive came from the middle layer of somewhat coarser and much more permeable and porous sand. Wherever this layer is absent, the air-drive had practically no effect in bringing about an increase in production.

NATURAL GASOLINE PRODUCTION

Several natural gasoline plants were in operation in the Bradford field between 1912 and 1926 that depended upon the local supply of natural gas. On account of the low permeability of the sand, vacuum pumps were not employed to any extent in connection with this industry. The application of a vacuum to the producing wells had little or no effect on the rate of oil production and did not increase the flow of gas sufficiently to make it profitable. Due to the normal decline in the gas output of the field and the increased consumption on the leases in connection with the flooding operations, the supply available for the extraction of natural gasoline had declined to such an extent by the end of 1926 that practically all of the plants were shut down and dismantled. In 1934 only one plant of the compression type of 550 gallons daily capacity was in operation in the Bradford field.

REFINING, PIPE LINE, AND TRANSPORTATION FACILITIES

During 1934 the refinery capacity of the Bradford district was equivalent to about two-fifths of the annual output of crude oil. There are four refineries, one in the eastern part of the city of Bradford, one just to the north of Foster Brook; a third, along the Allegheny valley at Eldred, a short distance east of the oil field; and a fourth, along Potato Creek below Smethport at Farmers Valley, also a short distance east of the field. Their names, capacities, and types according to products made are listed in Table 146.

Table 146. Petroleum refineries of the Bradford District.[3]

		Straight distillation		Cracking	
Company	Location	Daily capacity barrels	Type	Daily capacity barrels	Type
Bradford Oil Refining Co.	Foster Brook	2,300	Skimming and lube		
Kendall Refining Co.	Bradford	3,500	Complete	1,400	Dubbs
Pennsylvania Oil Products Refining Co.	Eldred	6,000	Do	500	Wade
Quaker State Oil Refining Co.	Farmers Valley	3,000	Do	1,500	Dubbs
Total		14,300			

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[3] G. R. Hopkins and E. W. Cochrane, Petroleum refineries, including cracking plants, in the United States, January 1, 1935; U. S. Bureau of Mines, I.C. 6850 pp. 22-23, September, 1935.

The Bradford Oil, Kendall, Pennsylvania Oil Products, and Quaker State Oil refining companies own and operate extensive gathering systems throughout large parts of the Bradford field to supply their own refineries with crude. In addition, the following companies are also purchasers and gatherers of crude oil in the district:

Bradford Transit Company, Forest Pipe Line Company, National Transit Company, New York Transit Company, United Refining Company, Vacuum Oil Company.

The Bradford Transit Company handles the largest volume of oil from the field. Its lines radiate throughout the district. Shipments can be made from the Bradford assembly points either southerly over the National Transit Company's system to refineries in central-western and southwestern Pennsylvania, or over the Tidewater Pipe Line Company's system to Bayway or Bayonne, New Jersey.

Bradford is on the main line of the Buffalo, Rochester and Pittsburgh Railroad, now part of the Baltimore and Ohio System, 77 miles south of Buffalo and 208 miles northeast of Pittsburgh by rail. The city is served also by branch lines of the Erie and Pennsylvania railroads. The Buffalo division of the Pennsylvania Railroad passes through Eldred at the eastern edge of the district.

ECONOMIC SITUATION

At the end of 1935 the Bradford field had produced 338,118,000 barrels of oil of a total value of approximately $543,728,000 at the wells. With an annual production of 13,183,322 barrels in 1935, it ranked twelfth among the leading pools of the country.[4] From the standpoint of total production it ranked eighth.

Table 147. Production of Pennsylvania-grade crude oil and its relation to total production of the United States, 1924-1934, inclusive.[5]

Year	Central and Eastern Ohio barrels	New York barrels	Pennsylvania barrels	West Virginia barrels	Total Pa.-grade barrels
1924	2,168,000	1,440,000	7,486,000	5,920,000	17,014,000
1925	2,242,000	1,695,000	8,097,000	5,763,000	17,797,000
1926	2,011,000	1,956,000	8,961,000	5,946,000	18,874,000
1927	2,346,000	2,242,000	9,526,000	6,023,000	20,137,000
1928	2,877,000	2,603,000	9,956,000	5,661,000	21,091,000
1929	2,654,000	3,777,000	11,820,000	5,574,000	23,425,000
1930	2,742,000	3,647,000	12,786,000	5,068,000	24,243,000
1931	2,184,000	3,363,000	11,876,000	4,470,000	21,893,000
1932	1,741,000	3,508,000	12,396,000	3,875,000	21,520,000
1933	1,594,000	3,181,000	12,607,000	3,815,000	21,197,000
1934	1,629,000	3,800,000	14,516,000	4,096,000	24,041,000

Year	Bradford district barrels	Percent Bradford of total Pennsylvania-grade production	Total crude oil production of U. S. barrels	Percent Penna.-grade of total U. S. production
1924	2,480,540	14.6	713,940,000	2.4
1925	2,747,620	15.4	763,743,000	2.3
1926	4,725,252	25.0	770,874,000	2.4
1927	5,793,707	28.8	901,129,000	2.2
1928	6,361,703	30.2	901,474,000	2.3
1929	8,137,125	34.7	1,007,323,000	2.3
1930	9,334,096	38.5	898,011,000	2.7
1931	8,812,133	40.3	851,081,000	2.6
1932	9,964,235	46.3	785,159,000	2.7
1933	10,125,458	47.8	905,656,000	2.3
1934	11,990,248	49.9	909,345,000	2.6

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[4] The Oil and Gas Journal, vol. 34, no. 37, p. 41, January 30, 1936.

[5] Pennsylvania-grade crude oil produced, 1924-33, by States. Statistical Appendix to Minerals Year Book, 1934, U. S. Bureau of Mines, p. 214, 1935.

Since 1921, the year that the practice of water-flooding became legalized, the Bradford district has been supplying a steadily increasing proportion of the total Pennsylvania-grade crude oil produced in the Appalachian province. This has increased from 14.6 percent in 1924 to 49.9 percent in 1934, as shown in Table 147. The relation of the total Pennsylvania-grade produc-

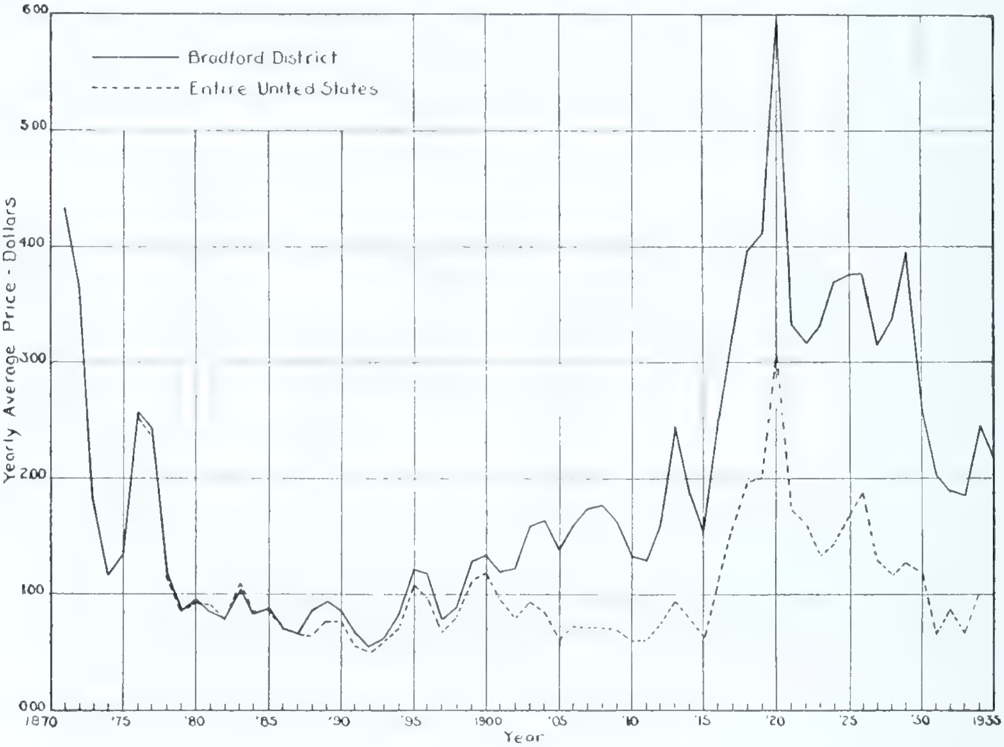

FIGURE 111. **Relation of yearly average price paid for Bradford crude oil to yearly average for entire United States.**

Table 148. Yearly average price paid for Bradford crude oil and for entire United States production.

Year	Bradford district	United States	Year	Bradford district	United States	Year	Bradford district	United States
1871	$4.34	$4.34	1893	$0.64	$0.60	1915	$1.563	$0.64
1872	3.64	3.64	1894	.838	.72	1916	2.505	1.10
1873	1.83	1.83	1895	1.223	1.09	1917	3.248	1.56
1874	1.17	1.17	1896	1.19	.96	1918	3.974	1.98
1875	1.35	1.35	1897	.788	.68	1919	4.123	2.01
1876	2.563	2.52	1898	.913	.80	1920	5.967	3.07
1877	2.42	2.38	1899	1.292	1.13	1921	3.328	1.73
1878	1.19	1.17	1900	1.353	1.19	1922	3.175	1.61
1879	.859	.86	1901	1.210	.96	1923	3.328	1.34
1880	.945	.94	1902	1.234	.80	1924	3.695	1.43
1881	.853	.92	1903	1.589	.94	1925	3.762	1.68
1882	.786	.78	1904	1.627	.86	1926	3.765	1.88
1883	1.054	1.10	1905	1.394	.62	1927	3.156	1.30
1884	.836	.85	1906	1.597	.73	1928	3.360	1.17
1885	.884	.88	1907	1.746	.72	1929	3.947	1.27
1886	.714	.71	1908	1.78	.72	1930	2.596	1.19
1887	.666	.67	1909	1.645	.70	1931	2.022	.65
1888	.87	.65	1910	1.336	.61	1932	1.881	.87
1889	.941	.77	1911	1.301	.61	1933	1.864	.67
1890	.866	.77	1912	1.60	.74	1934	2.461	1.00
1891	.669	.56	1913	2.463	.95	1935	2.177	
1892	.555	.51	1914	1.882	.81			

tion to the total of the entire United States, on the other hand, changed but little during this interval, representing about 2.5 percent of the latter.

Prior to 1900 the yearly average price paid for Bradford crude oil was practically the same as the average for the entire United States. With the opening up of the Spindle Top pool on the Gulf Coast of Texas and several important pools in California early in the present century, the average price for the entire country commenced to show a marked decline over the price received for Bradford crude. Although this difference has fluctuated considerably during the past 35 years, an inspection of Table 148 and Figure 111 shows that in general the trend in price received for Bradford crude oil has approximately paralleled the major trend for the country as a whole.

Early in the present century with the advent of the automobile, the producers of Pennsylvania-grade crude oil were in a position to command a premium price for their oil, not only because it was the source of superior quality lubricating oils but also because it yielded high percentages of straight run gasoline which proved to be an ideal fuel for the early type of gasoline engine. With the discovery of the cracking process and its extensive application to all types of crude oils in recent years, accompanied by changes in the design of automobile engines which made them more efficient by employing higher compressions, it was found that the straight run gasoline prepared from paraffin base petroleums knocked badly as compared to the cracked gasolines obtained from naphthene type crudes. Pennsylvania-grade crude oil, therefore, lost its advantage as far as gasoline production is concerned. Although the refiners of Pennsylvania-grade crude oil have met this situation by installing cracking plants and are now in a position to produce gasoline possessing the high anti-knock quality and other characteristics demanded by present day automobile engines, they have no particular advantage in this respect over the refiners of other types of crude oil.

According to Grisell[6], the Pennsylvania-grade crude oil refiner at present cannot sell gasoline west of Columbus, Ohio; east of Harrisburg, Pennsylvania; north of Rochester, New York; or more than halfway down into West Virginia. Freight plus high cost of crude make it impossible to compete with gasoline from other sources beyond these limits.

By modern methods of refining about 52 percent gasoline and kerosene, 25 percent fuel oil, naphthas, waxes, etc., and 23 percent high grade lubricating oil are obtained from Pennsylvania-grade crude. As Grisell points out, at present the average price of crude oil for the country as a whole determines largely the price that is obtained for 77 percent of each barrel of Pennsylvania-grade crude oil produced. The higher price per barrel which the Pennsylvania-grade crude oil producer must obtain in order to remain in business under present conditions now depends, therefore, almost entirely on the yield of 23 percent of high grade lubricating oils.

A comparison between the average unit cost and sales value of Pennsylvania-grade crude oil and the average for the United States is given in Table 149. The figures show that costs in the Appalachian district are about two and one-half times as high as the average for the whole country.

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[6] T. O. Grisell, Problems of eastern producers: Oil and Gas Jour., vol. 33, p. 55, Dec. 13, 1934.

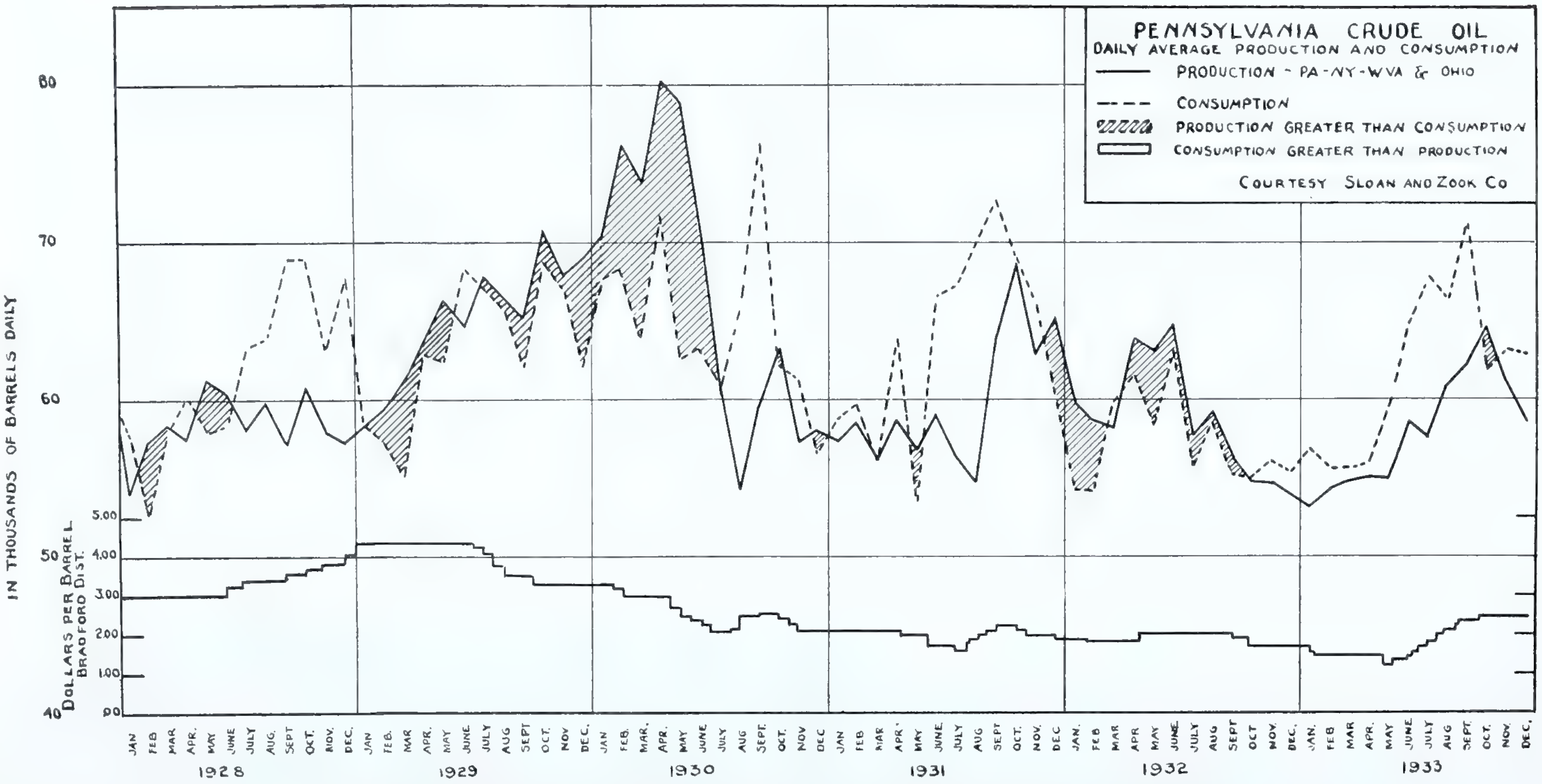

FIGURE 112. Relation of price to daily average production and consumption of Pennsylvania-grade oil by months, 1928-1933.

Table 149. Unit cost of production and sales value of Pennsylvania-grade crude oil and average of entire United States.[7]

Weighted average 1931-1934, inclusive	Average annual production-company interest cost base barrels	Net cost	Net cost including interest on invested capital	Average selling price
Pennsylvania grade				
New York	825,785	$1.526	$2.053	$2.054
Pennsylvania	8,580,132	1.556	1.965	2.056
West Virginia	2,369,234	1.749	2.116	1.686
Average entire United States	543,548,665	.688	.798	.787
Unit cost 1934				
New York	657,619	1.773	2.330	2.451
Pennsylvania	9,366,178	1.619	1.933	2.440
West Virginia	2,069,109	1.829	2.113	2.089
Average entire United States	532,381,320	.667	.775	.984

It has been quite generally conceded that the high-viscosity-index lubricating oils such as are made from Pennsylvania-grade paraffin-base crude oil are superior to other types and are necessary where the duties that the lubricant must perform are exacting. Much research work is at present underway to produce lubricating oils of the same high quality from other types of crude. Processes, such as hydrogenation and solvent extraction, have been developed in recent years to improve the quality of lubricating oils derived from other crudes. The producers and refiners of Pennsylvania-grade oil are fully aware of the effect that the increased competition with lubricants produced by these new processes may have on the structure of their industry and have taken steps to meet the situation. The Pennsylvania Grade Crude Oil Association maintains a research laboratory at Pennsylvania State College, one of whose functions is to further improve the quality of lubricants made from Pennsylvania-grade oil. Companies engaged in Pennsylvania-grade oil are spending large sums annually in modernizing their plants. That their efforts have not been in vain is witnessed by the fact that the lubricants produced in the Appalachian district increased from 15.3 percent of the total production of the United States in 1929 to 19.8 percent in 1934[8]. The production of lubricants in the United States in 1934 totaled 26,373,000 barrels.

In order to keep production in the Bradford district in line with consumption, it has been necessary on several occasions in recent years to prorate production. A voluntary curtailment program was first inaugurated on May 16, 1930 under the supervision of a conservation board. The Conservation Board functioned as a prorating body until October 15, 1931 when new contracts were made with the producers by the major pipe line companies serving the district, which permit the latter to determine the percentage of the base amount stipulated that they will run.

The importance of balancing production and consumption in order to maintain a profitable price is brought out by Figures 112 and 113 showing the relation of price to production and consumption of Pennsylvania-grade crude oil. Periods of over-production are invariably followed by a decline in price, and periods of under production by an increase in price.

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[7] Report on the cost of producing crude petroleum; Petroleum Admin. Board, U. S. Dept. Int., pp. 60-61, December, 1935.

[8] Minerals Year book, 1935, U. S. Bur. of Mines, p. 755, 1935.

In recent years there has been a pronounced tendency to consolidate the great number of small individually-operated properties in the Bradford field into larger units. The attractive prices offered, particularly just prior to 1930, and the large outlay of capital required to develop properties under the present intensive system of water-flooding have induced many of the smaller producers to sell their holdings to the larger companies. The distribution among producers according to size for the Pennsylvania portion of the Bradford field in 1933, compiled from data on file at the McKean County assessor's office, is given in Table 150.

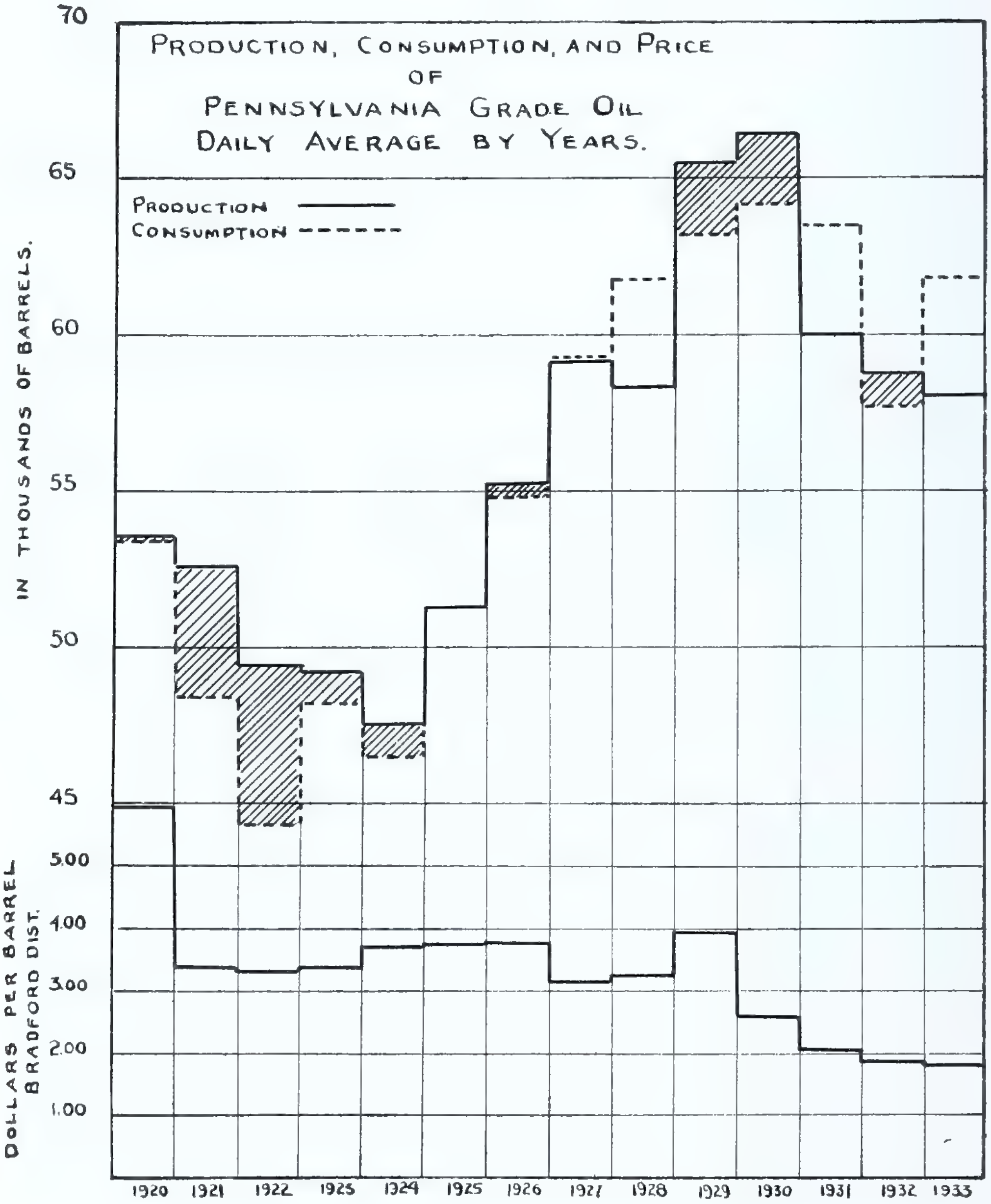

FIGURE 113. Relation of price to daily average production and consumption of Pennsylvania-grade oil by years, 1920-1933.

Table 150. Distribution of production among producers according to size in the Pennsylvania part of the Bradford Field in 1933.

Average daily production Barrels	Percent of total production	Number of producers	Average daily production Barrels	Percent of total production	Number of producers
Less than 10	5.1		100 to 500	14.1	18
10 to 25	12.1	138	500 to 1000	10.6	4
25 to 50	7.7	62	1000 or more	42.3	4
50 to 100	8.1	35			

The production and refining of crude oil is today the basic industry of McKean County. Between 1920 and 1930 the population of McKean County rose from 48,934 to 55,167, an increase of 13 percent[9].

It was during this interval that the present method of intensive water flooding was developed in the Bradford field. During that period the population of the Bradford oil field increased 37 percent; in marked contrast, the population outside the oil field declined 12 percent. In the townships included in the Bradford field, the oil producers pay from 70 to 75 percent of the local taxes.

RESERVES AND FUTURE LIFE OF FIELD

A weighted average recovery per acre-foot of oil-producing sand by present flooding methods has been calculated for each of the different parts into which the Bradford pool can be divided. These averages have been used in estimating the total oil that can be recovered from the pool by water-flooding as now practiced. The results are given in Table 151.

Table 151. Estimated total oil recoverable by present methods of water-flooding from the Bradford pool.

A. Average thickness of oil-bearing sand.*

B. Oil remaining after natural production had been removed but before water-flooding started*.

C. Estimated average recovery per acre-foot by water-flooding.

D. Estimated recovery by water-flooding.

		A	B	C	D
Part of pool	Acres	Feet	Barrels	Barrels	Barrels
Northeast area	22,500	30	331,790,000	185	124,875,000
Northwest lobe	13,500	29	191,100,000	145	56,767,000
Southeast lobe	14,000	26	191,350,000	150	54,600,000
Knapp dome	7,000	31	76,110,000	80	17,360,000
Rixford dome	1,500	28	14,730,000	80	3,360,000
Marginal areas	25,500	22	241,290,000	85	47,685,000
	84,000		1,046,370,000		304,647,000

*See Table 61.

The total production of the Bradford pool by methods utilizing the energy inherent in the reservoir itself is estimated at 203,600,000 barrels, making the total oil originally present in the pool equivalent to 1,249,970,000 barrels. According to these figures, 16 percent of the oil originally present has been recovered by natural methods and another 24 percent will have been recovered after the entire pool has been watered out by the methods of water-flooding now in use.

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[9] Fifteenth Census of the United States: 1930, vol. 1, Population, Bur. of the Census, pp. 928, 935 and 950, 1931.

At the end of 1936, 110,250,000 barrels of oil had already been recovered by water-flooding as distinguished from natural production, leaving 194,397,000 barrels still to be recovered by flooding. The 1936 production was 14,569,740 barrels. At that rate the remaining reserve recoverable by present production methods will last another 13 years.

According to the above estimates, 60 percent of the oil originally in the Bradford pool will remain after the entire pool has been watered out by the present system of water-flooding. It is hardly conceivable, however, that the present methods of water-flooding will not be still further improved before that stage is reached so that the recovery factor will probably be somewhat larger. The figure given represents an average for the entire pool. In those portions of the field where sand conditions are exceptionally favorable, considerably higher recoveries are already being obtained, but even in these aras large volumes of oil remain in the sand after the economic limit by present methods of production has been reached. Whether it will be possible at some future time to recover any considerable percentage of this remaining oil will depend not only on future technological developments but also on economic conditions. The price that can be obtained for the oil will be an important factor.

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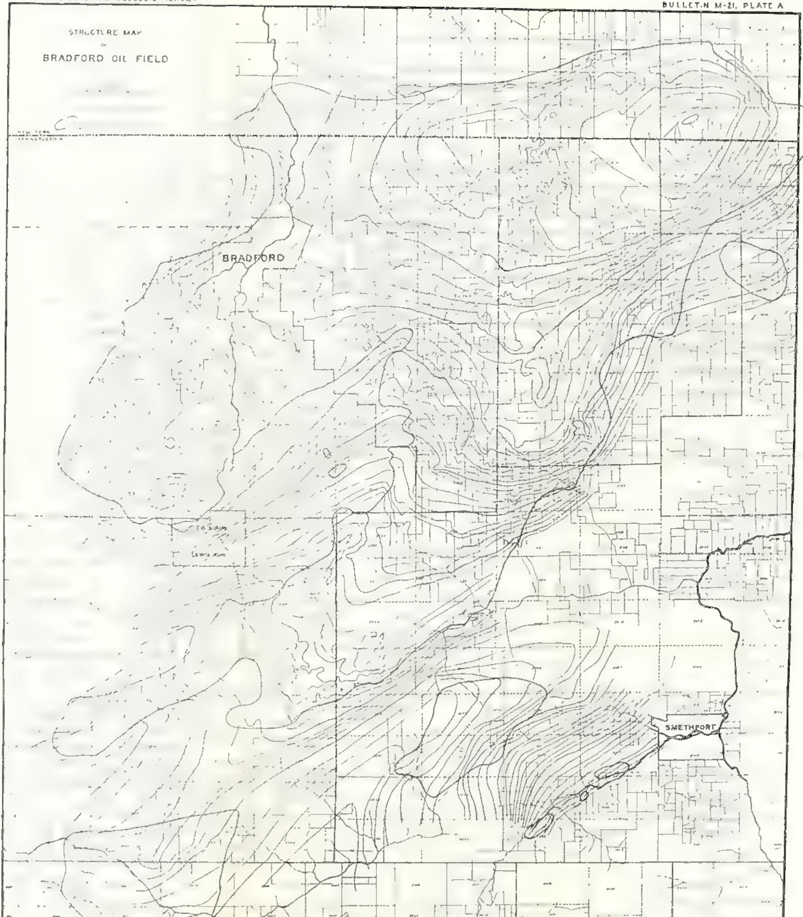
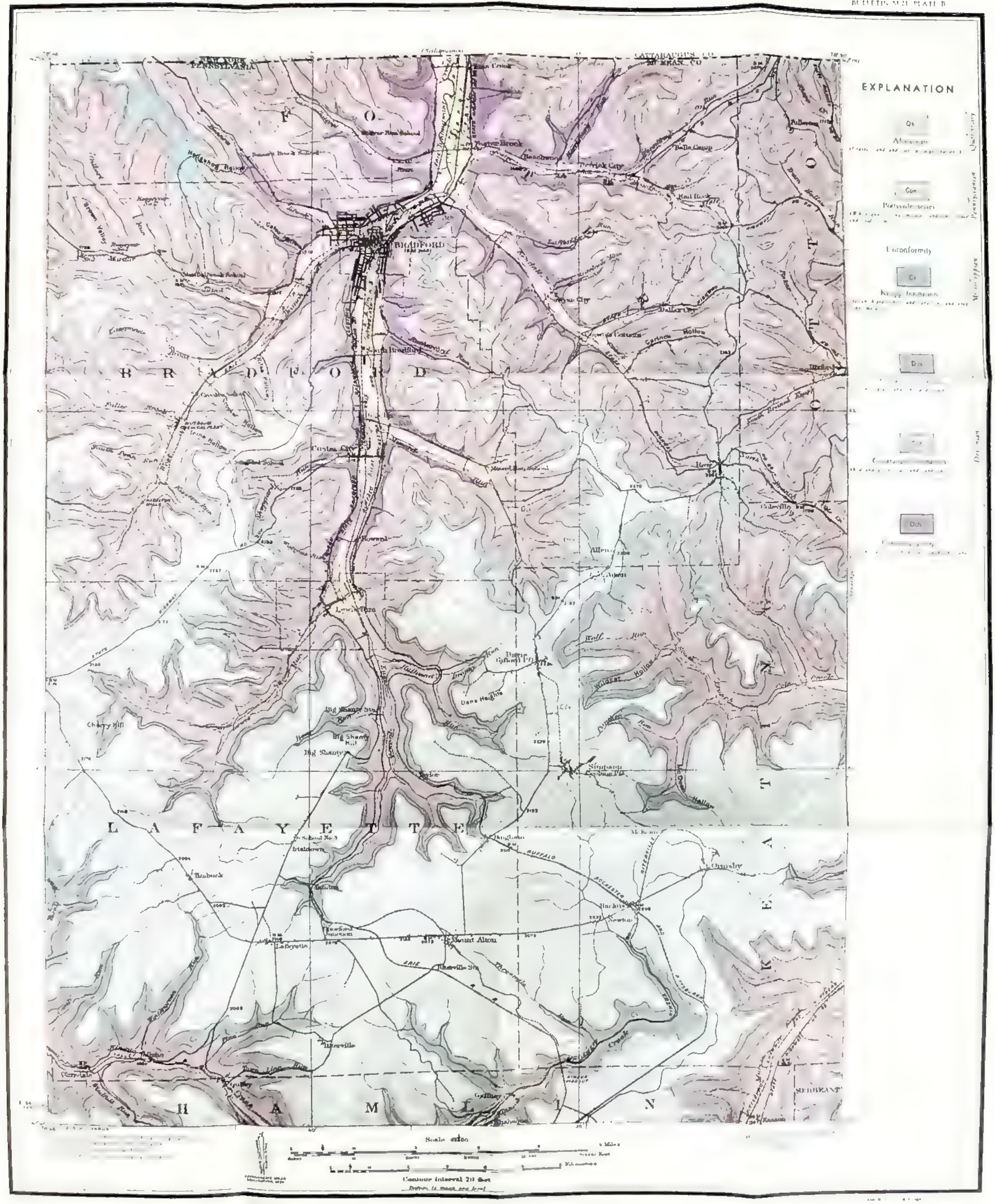
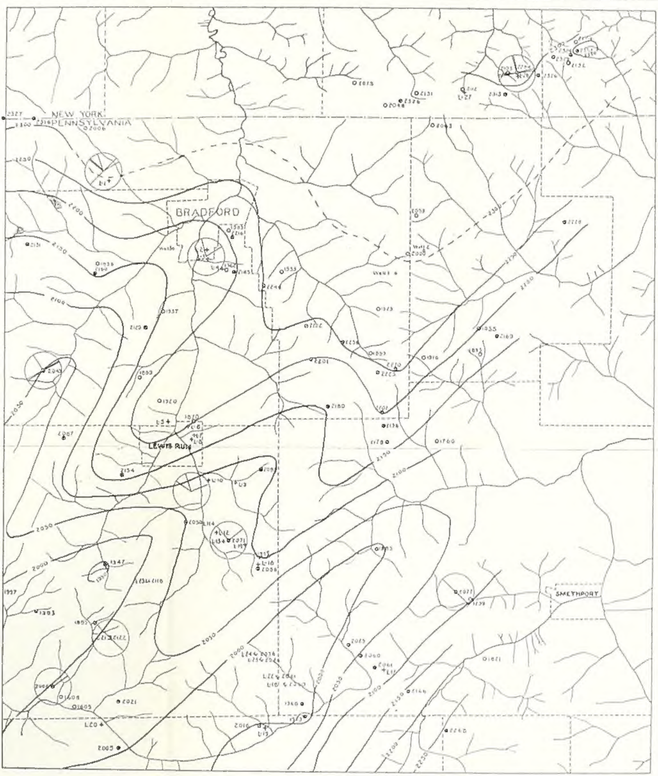
PENNSYLVANIA
TOPOGRAPHIC AND GEOLOGIC SURVEY

BULLETIN M-21, PLATE A



AREAL GEOLOGY
BRADFORD QUADRANGLE





LEGEND

- + Locality referred to in text.
- ⊓ Elevation Marker test above sea level.
- ● Elevation base of Olean above sea level.
- ○ Elevation top of Cattaraugus above sea level.

OUTCROP AND SURFACE STRUCTURE MAP
OF
BRADFORD DISTRICT

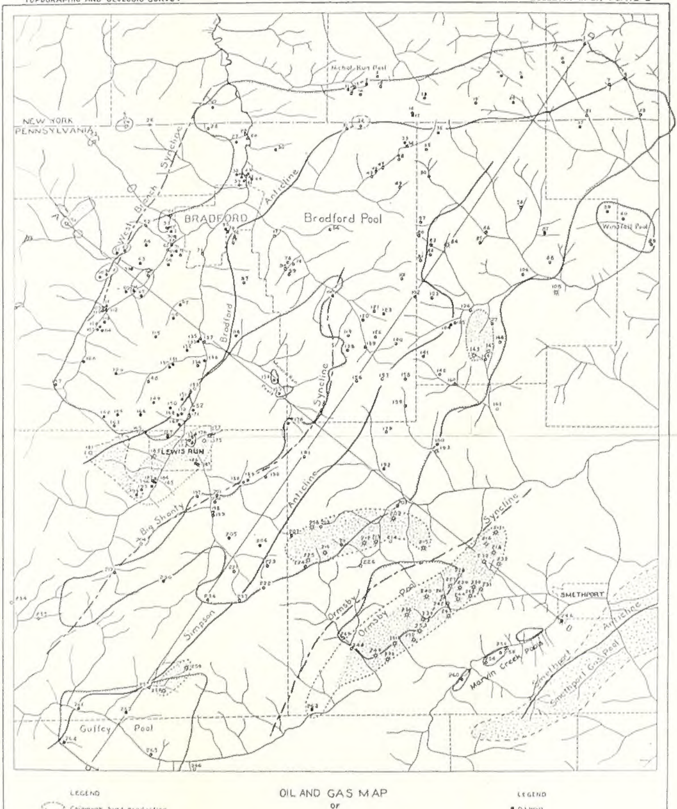
Scale
0 1 2 3 4 5 Miles

LEGEND

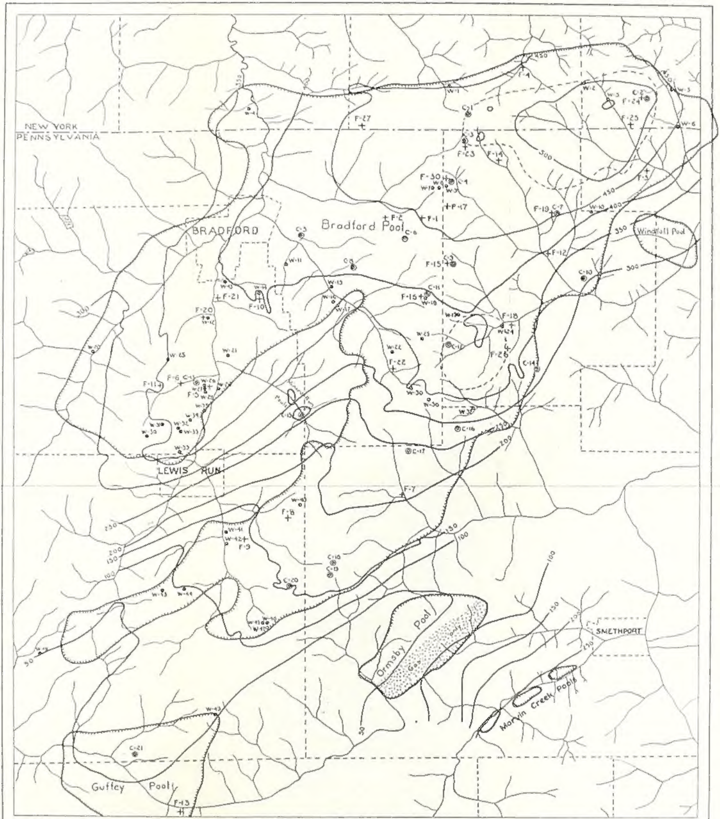
Structure contours on base of Olean.

Strikes of prominent joints.

Chas. R. Fettke
1934



OIL AND GAS MAP
OF
BRADFORD DISTRICT



LEGEND

350 Structure contours on top of Bradford Third Sand. Elevation above sea-level in feet.

Approximate limits of production from Bradford Third sand.

Approximate limits of gas sand in upper part of Bradford Third sand.

STRUCTURE MAP
OF
BRADFORD DISTRICT

Scale
0 1 2 3 4 5 Miles

LEGEND

C-1 ● Core of Bradford Third sand described in text.

W-1 • Cuttings of Bradford Third sand described in text.

F-1 + Approximate location of Fired discussed in text.

Chas. R. Fettke
1934